台灣農業研究

JOURNAL OF TAIWAN AGRICULTURAL RESEARCH

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Research Article

Synergistic Effect of Additional Gas on the Toxicity of Phosphine to *Sitophilus oryzae* and *Sitophilus zeamais* (Coleoptera: Dryophthoridae)

Wen-Bin Feng[1], Chi-Yang Lee[1], Tai-Chuan Wang[2], and Me-Chi Yao[3,*]

Abstract

Feng, W. B., C. Y. Lee, T. C. Wang, and M. C. Yao. 2024. Synergistic effect of additional gas on the toxicity of phosphine to *Sitophilus oryzae* and *Sitophilus zeamais* (Coleoptera: Dryophthoridae). J. Taiwan Agric. Res. 73(1):1–10.

Sitophilus spp. is the most serious pest in imported brown rice warehouses, and its phosphine resistance has been observed in Taiwan. To overcome the efficiency decline of phosphine fumigation to *Sitophilus* beetles, phosphine fumigation with additional gas is the most noticed practice internationally. In this study, we evaluated the toxicity increase of phosphine in the presence of additional 10–20% of CO_2, O_2, or N_2 to *Sitophilus* beetles for 20 h or 72 h of fumigation. We found that there was no synergism between phosphine and additional gas for phosphine-resistant *Sitophilus oryzae* (Linnaeus) strains with 20 h fumigation. However, when the fumigation period prolonged to 72 h, the LC_{50} of phosphine with additional 10 or 20% of CO_2, or N_2 decreased from 13.8 to 2.9–11.0 μg L^{-1} for Houbi strain of *S. oryzae*. We consider that additional CO_2, and N_2 can potentially enhance the toxicity of phosphine against phosphine-resistant stored-product pests in the imported rice warehouse.

Key words: *Sitophilus*, Phosphine, CO_2, O_2, N_2.

INTRODUCTION

Based on the principle of international trade fairness requested by World Trade Organization (WTO), Taiwan must import a certain amount of brown rice or white rice from abroad. The 8% of people's livelihood demand of rice are imported per year, and 65% of which are purchased by the government and transported to designated warehouses. They will then be stored for half a year to two years as the emergency grain. Since Taiwan is in the subtropical region where the temperature and humidity are high and no clearly divided four seasons that make the warehouses an ideal environment for the growth of pests. Besides, most warehouses for imported rice were rebuilt from old fertilizer warehouses. Their temperature and humidity are always higher than outsides that tend to provide conditions for better reproduction of stored-product insects. As a result, the imported rice could be infested with the stored-product insects during three-month of storage. Among the stored-product pests, *Sitophilus* spp. are the most serious pests in Taiwan, such as the rice weevil (*S. oryzae*) and corn weevil (*S. zeamais* Motchulsky).

Without the rice husk protection during storage, the *Sitophilus* beetles can easily bore deep holes with their mouthparts to lay eggs

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inside. After hatching, the larvae feed and grow inside the grains producing debris which further leads to the outbreak of secondary pest infestation such as the rusty grain beetle (*Cryptolestes ferrugineus* Stephens), saw-toothed grain beetle (*Oryzaephilus surinamensis* Linnaeus), and foreign grain beetle (*Ahasverus advena* (Waltl)). Moreover, since the imported rice is often stored in ton bags and the larva of *Sitophilus* beetle is internal feeder, the damage and loss of rice is barely observable from the surface of storage bags. When the weevil adults emerged from rice, huge loss of rice had occurred.

Currently, 57% aluminum phosphide or 66% magnesium phosphide tablets are used to produce phosphine to control the outbreaks of stored-product insects in warehouses during the storage periods. However, Yao *et al*. (2022) tested the phosphine susceptibility of 21 strains of rice weevil and 17 strains of corn weevil collected in imported brown rice warehouses, and found that rice weevils from 5 locations (Hukou, Ershuei, Huatan, Xihu, and Houbi) had developed phosphine resistance at higher than moderate level. The development of phosphine resistance in rice weevils may gradually lead to the control failure using phosphine fumigation. Consequently, the fumigation operator may have to put more aluminum phosphide tablets into the warehouses to avoid phosphine fumigation failure. This vicious circle will not only increase the selection pressure of phosphine resistance to stored-product pests in the wild, but also increase the frequency of phosphine fumigation application that in turn leads to the increase of financial burden on the government (Agriculture and Food Agency).

To overcome the decline of phosphine fumigation efficiency against the phosphine-resistant stored-product pests, several strategies had been recommended including increasing ambient temperature during fumigation, using alternate fumigants, and fumigation with additional gas (Nayak & Collins 2008; Boopathy *et al*. 2022). Among these recommendations, addition of gases such as O_2, CO_2, and N_2 to enhance the fumigation effect of phosphine is the most noticed practice internationally (Athié *et al*. 1998; Liu 2011; Manivannan *et al*. 2016; Constantin *et al*. 2020; Sakka *et al*. 2020). In the present study, several phosphine-resistant and susceptible strains of rice weevil and corn weevil from the collection of Yao *et al*. (2022) were used. The median lethal concentration (LC_{50}) of weevils to phosphine for 20 h and 72 h were measured with or without 10 or 20% of individual CO_2, O_2, or N_2, respectively. The potential improving strategies of phosphine fumigation against the phosphine-resistant stored-product pests in Taiwan will then be suggested based on the results of the three added gases in improving the phosphine insecticidal effect.

MATERIALS AND METHODS

Sampling site and insect rearing

The species of *Sitophilus* weevils used in this study were *S. oryzae* and *S. zeamais*. All strains of both species were collected from warehouses where the imported brown rice was kept. The adults of phosphine-susceptible strain of *S. oryzae* were collected from Yilan and the Lab strain (reared for more than 10 years without insecticide treatments), and the phosphine-resistant strains were collected from Hukou, Ershuei, Huatan, Xihu, and Houbi. The adults of phosphine-susceptible strains of *S. zeamais* were collected from Xinying, Longtian, and Tainan. Weevil adults were reared in a plastic container (radius: 12 cm, height: 5 cm) with oatmeal as food source and maintained in environmental chambers with temperature set at 27 ± 1℃ and relative humidity at 70 ± 5%, and 24-hour darkness.

Synergism of fumigation between additional gas and phosphine

The 57% aluminum phosphide tablets were manufactured by Detia Freyberg GmbH (Laudenbach, Germany), and purchased from GIANT BEAR Company (Taipei, Taiwan).

The synergism experiments were slightly modified from the recommended FAO phosphine bioassay methods (Anonymous 1975). First, 3 g of 57% aluminum phosphide tablets were put into a glass jar with 5% sulfuric acid in a 20 L desiccator (called gas production site) to generate phosphine gas and waited for 1.5 h for the chemical reaction to complete. For each bioassay, 30 F_2 generation unsexed weevil adults (1-to-2-week-old) were placed in a ventilated plastic container (radius: 3.5 cm, height: 5.5 cm), then put into another 20 L desiccator (called tests site) for phosphine fumigation. For each bioassay, there were 3 replications with a control without phosphine fumigation. The 10 or 20% CO_2, O_2, and N_2 were injected through air flow meter respectively, then the required dose of phosphine gas was injected to the tests site with gas tight syringes. The phosphine specificity detector and tester (Uniphos Envirotronic Pvt Ltd, Valsad, India) were used to measure the phosphine concentration. All desiccators were placed in a controlled temperature space (27 ± 1℃, 75 ± 10% RH) and the fumigations were conducted for 20 h and 72 h, respectively. After completion of the fumigation, the phosphine gas and the other additional gases were removed with the fume hood. The weevil adults were fed with oatmeal for 24 h to allow time for them to recover, and the mortality (no response to touch) was observed after the recovery period. The Vaseline was used to insure the tightness of desiccators while the phosphine detector was used to detect the escaping of phosphine gas.

Statistical analysis

All analyses were performed using SPSS program (Version 22). The Probit analysis was used to analyze the concentration-mortality data, and obtain the LC_{50} and 95% fiducial limits (FL) of LC_{50} of each treatment. The relative ratios of phosphine fumigation toxicity were then calculated by the LC_{50} with the extra gas added divided by the LC_{50} without the extra gas added for each strain. A relative ratio > 1.00 indicated decreased phosphine toxicity and a relative ratio < 1.00 indicated increased phosphine toxicity.

RESULTS

Synergism of 20 h co-fumigation

As compared to fumigation with phosphine alone for 20 h in *S. oryzae*, results showed that co-fumigation with 10–20% CO_2 resulted in the LC_{50} decreasing to 0.49- to 0.93-fold for Yilan and lab strains (Table 1). However, the LC_{50} increased to 1.00- to 1.83-fold for all phosphine-resistant strains except the Huatan strain. As phosphine co-fumigation with 10% N_2, the LC_{50} decreased to 0.72- to 0.81-fold for Huatan and Hukou strains (Table 1). However, the LC_{50} of phosphine with 20% N_2 was similar to that with only phosphine for Huatan strain. The LC_{50} of phosphine with 10–20% O_2 increased to 1.27- to 2.99-fold for all strains except for the lab strain at 10% O_2 (Table 1).

In *S. zeamais*, results showed that co-fumigation with 10–20% CO_2 resulted in decreases of LC_{50} to 0.22- to 0.60-fold for Longtian and Tainan strains, while the LC_{50} of phosphine with 10–20% CO_2 did not change for the Xinying strain (Table 2). The LC_{50} of phosphine with 10–20% N_2 increased to 1.38- to 1.64-fold for all strains except for the all Longtian treatments and Tainan + 10% N_2 (Table 2). For the Longtian and Tainan strain of corn weevils, the LC_{50} of phosphine with 10–20% O_2 decreased to 0.40- to 0.91-fold (Table 2). Conversely, the LC_{50} of phosphine with 10–20% O_2 increased to 1.44- to 1.76-fold for Xinying strain.

Synergism of 72 h co-fumigation

Results of 72 h fumigation for the Houbi strain of *S. oryzae* (Table 3) indicated that the LC_{50} of phosphine with 10–20% CO_2 or N_2 decreased to 0.21- to 0.80-fold as compared to that with only phosphine. However, the LC_{50} of phosphine with 10–20% O_2 increased to 1.10- to 1.70-fold.

Table 1. The LC_{50} of *Sitophilus oryzae* to phosphine co-fumigation with 10 or 20% CO_2, N_2 or O_2 for 20 h.

Treatments	N^z	LC_{50} (95% FL^y) (μg L^{-1})	Slope	Chi-square	Relative Ratio^x
Lab (RR = 2.22^w)	450	3.3 (2.9–3.9)	2.30	30.22	1.00
Lab + 10% CO_2	450	2.6 (2.2–3.0)	2.43	8.54	0.79
Lab + 20% CO_2	450	1.6 (1.3–1.8)	1.80	19.59	0.49
Lab + 10% N_2	450	4.0 (3.6–4.5)	3.21	15.08	1.21
Lab + 20% N_2	450	3.2 (2.6–3.9)	3.23	26.66	0.97
Lab + 10% O_2	450	3.1 (2.8–3.5)	3.14	14.59	0.94
Lab + 20% O_2	450	4.2 (3.8–4.7)	3.87	2.72	1.27
Yilan (RR = 1.00)	450	1.5 (0.9–2.2)	2.46	970.54	1.00
Yilan + 10% CO_2	450	1.4 (0.9–1.8)	1.87	33.59	0.93
Yilan + 20% CO_2	450	0.9 (0.6–1.2)	1.62	24.32	0.60
Yilan + 10% N_2	450	2.3 (1.6–3.2)	2.77	64.64	1.53
Yilan + 20% N_2	450	3.3 (2.3–4.3)	2.37	53.09	2.20
Yilan + 10% O_2	450	3.3 (3.0–3.6)	4.81	6.44	2.20
Yilan + 20% O_2	450	3.4 (3.1–3.7)	4.30	12.53	2.27
Ershuei (RR = 15.13)	540	22.7 (14.8–35.7)	3.00	65.21	1.00
Ershuei + 10% CO_2	450	41.6 (38.7–44.5)	4.52	3.43	1.83
Ershuei + 20% CO_2	450	29.7 (24.5–34.7)	2.60	27.17	1.31
Ershuei + 10% N_2	450	44.1 (39.1–50.0)	2.37	6.18	1.94
Ershuei + 20% N_2	540	37.4 (30.9–43.9)	1.60	17.33	1.65
Ershuei + 10% O_2	540	46.4 (40.9–51.8)	2.08	10.17	2.04
Ershuei + 20% O_2	450	30.6 (26.3–34.8)	2.29	1.15	1.35
Huatan (RR = 17.47)	450	26.2 (21.2–35.2)	1.35	10.96	1.00
Huatan + 10% CO_2	540	16.7 (12.8–20.5)	1.36	1.93	0.64
Huatan + 20% CO_2	540	26.3 (21.1–32.2)	1.26	7.81	1.00
Huatan + 10% N_2	540	18.8 (15.1–22.4)	1.59	6.23	0.72
Huatan + 20% N_2	450	27.9 (19.2–35.5)	1.16	3.47	1.06
Huatan + 10% O_2	540	76.1 (60.4–104.0)	0.92	12.29	2.90
Huatan + 20% O_2	540	78.3 (69.5–88.1)	2.25	6.11	2.99
Hukou (RR = 25.87)	540	38.8 (35.3–42.4)	3.25	20.45	1.00
Hukou + 10% CO_2	450	51.7 (40.9–73.6)	1.15	3.94	1.33
Hukou + 20% CO_2	450	59.4 (47.5–85.4)	1.27	4.43	1.53
Hukou + 10% N_2	450	31.5 (26.7–36.3)	2.03	6.25	0.81
Hukou + 20% N_2	450	55.9 (46.4–72.7)	1.52	9.38	1.44
Hukou + 10% O_2	540	98.5 (76.2–149.0)	0.91	18.40	2.54
Hukou + 20% O_2	540	93.9 (85.1–104.0)	2.72	6.14	2.42
Xihu (RR = 36.40)	540	54.6 (46.0–66.8)	1.57	14.50	1.00
Xihu + 10% CO_2	450	61.0 (51.4–78.1)	1.73	7.67	1.12
Xihu + 20% CO_2	540	85.1 (65.9–134.0)	1.14	17.22	1.56
Xihu + 10% N_2	540	91.3 (77.7–116.0)	2.15	13.25	1.67
Xihu + 20% N_2	540	68.2 (55.1–94.6)	1.94	29.77	1.25
Xihu + 10% O_2	720	122.0 (94.5–185.0)	1.10	6.59	2.23

Table 1. The LC_{50} of *Sitophilus oryzae* to phosphine co-fumigation with 10 or 20% CO_2, N_2 or O_2 for 20 h. (continued)

Treatments	N[z]	LC_{50} (95% FL[y]) (μg L^{-1})	Slope	Chi-square	Relative Ratio[x]
Xihu + 20% O_2	630	73.6 (66.8–81.4)	2.51	9.51	1.35
Houbi (RR = 49.20)	690	73.8 (54.5–114.0)	1.14	19.30	1.00
Houbi + 10% CO_2	450	103.0 (59.6–134.7)	1.03	37.33	1.40
Houbi + 20% CO_2	450	106.0 (102.0–112.0)	6.50	11.06	1.44
Houbi + 10% N_2	720	148.0 (134.0–170.0)	3.32	9.84	2.01
Houbi + 20% N_2	720	147.0 (133.0–168.0)	3.31	11.57	1.99
Houbi + 10% O_2	450	120.0 (110.0–137.0)	4.33	8.90	1.63
Houbi + 20% O_2	540	122.0 (112.0–137.0)	3.58	4.49	1.65

[z] Number of insects tested.
[y] Estimated lethal concentration values with fiducial limits (FL).
[x] For each strain, the relative ratio = LC_{50} of additional gas treatment divided by the LC_{50} of no additional gas treatment. For example, the relative ratio of Lab + 10% CO_2 = 2.6 (LC_{50} of Lab + 10% CO_2)/3.3 (LC_{50} of Lab) = 0.79.
[w] RR = Resistance ratio.

Table 2. The LC_{50} of *Sitophilus zeamais* to phosphine co-fumigation with 10 or 20% CO_2, N_2 or O_2 for 20 h.

Treatments	N[z]	LC_{50} (95% FL[y]) (μg L^{-1})	Slope	Chi-square	Relative ratio[x]
Xinying (RR = 1.32[w])	450	2.5 (1.5–3.7)	2.61	95.48	1.00
Xinying + 10% CO_2	450	2.5 (2.2–3.0)	2.67	19.72	1.00
Xinying + 20% CO_2	450	2.5 (2.0–3.1)	2.43	28.36	1.00
Xinying + 10% N_2	450	4.1 (3.8–4.5)	0.57	1.81	1.64
Xinying + 20% N_2	450	4.0 (3.5–4.5)	2.92	13.45	1.60
Xinying + 10% O_2	450	3.6 (2.7–4.6)	2.85	39.93	1.44
Xinying + 20% O_2	450	4.4 (3.8–5.1)	2.42	15.45	1.76
Longtian (RR = 5.32)	450	10.1 (8.8–11.8)	1.92	16.24	1.00
Longtian + 10% CO_2	450	2.9 (2.5–3.3)	2.64	13.58	0.29
Longtian + 20% CO_2	450	2.2 (1.9–2.5)	2.54	10.36	0.22
Longtian + 10% N_2	450	4.9 (3.9–6.0)	2.52	22.77	0.49
Longtian + 20% N_2	450	6.4 (5.7–7.1)	3.32	14.23	0.63
Longtian + 10% O_2	450	4.0 (3.2–4.9)	2.92	31.18	0.40
Longtian + 20% O_2	450	7.1 (5.3–10.4)	1.92	42.90	0.70
Tainan (RR = 6.16)	540	11.7 (9.6–15.1)	1.79	6.18	1.00
Tainan + 10% CO_2	450	5.3 (4.3–6.5)	2.50	24.38	0.45
Tainan + 20% CO_2	450	7.0 (4.9–11.5)	1.24	23.74	0.60
Tainan + 10% N_2	450	8.3 (6.1–12.7)	1.26	30.90	0.71
Tainan + 20% N_2	450	16.1 (11.0–32.2)	0.99	50.34	1.38
Tainan + 10% O_2	450	7.9 (6.1–11.0)	2.10	24.52	0.68
Tainan + 20% O_2	450	10.7 (8.9–13.7)	1.41	12.52	0.91

[z] Number of insects tested.
[y] Estimated lethal concentration values with fiducial limits (FL).
[x] For each strain, the relative ratio = LC_{50} of additional gas treatment divided by the LC_{50} of no additional gas treatment.
[w] RR = Resistance ratio.

Table 3. The LC_{50} of *Sitophilus oryzae* to phosphine co-fumigation with 10 or 20% CO_2, N_2 or O_2 for 72 h.

Treatments	N[z]	LC_{50} (95% FL[y]) (μg L^{-1})	Slope	Chi-square	Relative ratio[x]
Houbi (RR = 49.20[w])	450	13.8 (11.4–16.7)	1.56	8.52	1.00
Houbi + 10% CO_2	450	6.8 (5.2–8.6)	1.47	10.71	0.49
Houbi + 20% CO_2	450	2.9 (1.6–4.3)	0.92	4.52	0.21
Houbi + 10% N_2	450	11.0 (9.2–13.0)	1.77	7.14	0.80
Houbi + 20% N_2	450	10.5 (6.7–15.3)	2.08	24.08	0.76
Houbi + 10% O_2	450	15.2 (9.6–25.0)	2.24	27.37	1.10
Houbi + 20% O_2	450	23.5 (19.2–29.8)	1.80	12.13	1.70

[z] Number of insects tested.
[y] Estimated lethal concentration values with fiducial limits (FL).
[x] For each strain, the relative ratio = LC_{50} of additional gas treatment divided by the LC_{50} of no additional gas treatment.
[w] RR = Resistance ratio.

DISCUSSION

Since 1975, reports indicated that additional gases such as CO_2, N_2, and O_2 could potentially enhance the toxicity of phosphine against the phosphine-resistant stored-product pests. Athié *et al*. (1998) indicated that phosphine fumigation for 20 h with additional 10–20% CO_2 decreased the LC_{50} of phosphine to 0.11- to 0.90-fold for phosphine-resistant *S. oryzae* and *Rhyzopertha dominica* (L.). Constantin *et al*. (2020) found that phosphine fumigation for 48 h with additional 30.99% CO_2 decreased the LC_{50} of phosphine to 0.12-fold for phosphine-resistant *C. ferrugineus* in Australia. The increased toxicity of phosphine with CO_2 was also found in the red flour beetle (*Tribolium castaneum* (Herbst)), the wheat weevil (*Sitophilus granarius* (L.)), and the flour mill beetle (*Cryptolestes turcicus* (Grouvelle)) (Kashi & Bond 1975; Rajendran & Muthu 1989; Ren *et al*. 1994). In addition, the decreased reproductive rates of the survival beetles after co-fumigation of phosphine and CO_2 were observed by Constantin *et al*. (2020) when compared to the control group. However, the fumigation of phosphine with 10–20% CO_2 did not enhance the toxicity of phosphine to all phosphine-resistant strains of the rice weevil and the LC_{50} values increased to 1.12- to 1.83-fold as compared with that of phosphine alone for 20 h fumigation in this study. But phosphine fumigation with 10–20% CO_2 decreased the LC_{50} value of Houbi strain to 0.21- to 0.49-fold as the fumigation time was extended to 72 h. Lambkin (2001) indicated that there was no synergistic effect between phosphine and 10% CO_2 to phosphine-resistant *R. dominica* unless the fumigation time was prolonged to 72 h. Wong-Corral *et al*. (2013) reported that 5 d of co-fumigation between phosphine and 50–90% CO_2 were needed to reach 100% mortality for all developmental stages of the cowpea weevil (*Callosobruchus maculatus* Fabricius). Other studies reported that fumigation toxicity of phosphine cannot be boosted with addition of 5–40% CO_2 in short fumigation periods (Rajendran 1990; Ren *et al*. 1994). By contrast, Valizadegan *et al*. (2012) indicated that the fumigation periods required for killing the immature stages of *O. surinamensis*, *Lasioderma serricorne* (Fabricius), and *Plodia interpunctella* (Hubner) could be reduced to 1 d as the phosphine fumigation was applied with an addition of 24% CO_2. Obviously, the effect of fumigation time on the toxicity of phosphine differs among the developmental stages of insects and species. However, the reasons about the differences of the co-fumigation time in enhancing the phosphine toxicity have not been mentioned yet.

There are 2 possible mechanisms for enhancing the phosphine toxicity with additional CO_2. One is to increase the metabolic rate of

aerobic respiration, thereby increasing the toxicity of phosphine (Kashi & Bond 1975). The other one is to promote the opening of the insect spiracle to increase gas exchange rates, thus enhancing the amount of phosphine flowing into the insect body (McGovran 1932; Mitcham *et al*. 2006). However, it does not mean that the higher the concentration of CO_2, the better the synergistic effect. Some studies have found antagonism between high concentration of CO_2 and phosphine. Kashi & Bond (1975) indicated that adding 60–80% CO_2 did not inhibit the insect's aerobic metabolism which might be related to narcosis (Winks 1985) that finally led to increased resistance in insects to phosphine. The key point for synergism between CO_2 and phosphine might be the proportions of CO_2 and O_2 in the fumigation space. Constantin *et al*. (2020) speculated that the proportions of CO_2 and O_2 in the space should be 25–35% and 8–15%, respectively that led to the synergism between CO_2 and phosphine. However, differences of phosphine toxicity caused by the ratio of CO_2 and O_2 were rarely investigated.

The present study indicated that the fumigation periods could affect the synergistic effects between CO_2 and phosphine. This phenomenon may be related to phosphine resistance. The mechanisms of phosphine resistance were known to include structural changes in dihydrolipoamide dehydrogenase (DLD) (Zuryn *et al*. 2008; Schlipalius *et al*. 2012; Chen *et al*. 2015), decreased respiratory rate (Pimentel *et al*. 2007, 2009), active excretion of phosphine (Price 1984; Chaudhry & Price 1992; Pratt 2003), and upregulation of detoxification enzyme genes (Oppert *et al*. 2015; Yang *et al*. 2018; Wang *et al*. 2020). Among the mechanisms, decreased respiratory rate and active excretion of phosphine may have negative effects on the additional CO_2 and N_2. When the phosphine-resistant insects are in a space with high concentrations of CO_2 or N_2, the phosphine-resistance mechanisms in these insects might block the flow of the gas into their body that resulted in no synergism in short fumigation periods, or promote the over-expression of phosphine-resistant mechanisms that eliminated phosphine toxicity. Other studies indicated that insects may try to adapt to the high CO_2 concentration by minimizing the metabolic activity in the short fumigation period (Blomberg & Siegbahn 2014; Levy-de la Torre *et al*. 2018). However, since insects could not maintain the low respiration rate with slow metabolic activity and excludability of gas when the fumigation periods prolonged to 72 h, that finally led to the synergism between CO_2 and phosphine. Nevertheless, further evidence is needed.

In summary, we reported that co-fumigation of phosphine with 10–20% CO_2 or N_2 for 72 h could enhance the toxicity. The fumigation periods in imported rice warehouses are mostly 7–14 d, which is much longer than the fumigation periods conducted in the present study. In addition, CO_2 and N_2 are being considered as safe gases because of their low toxicity to human and environment. On the other hand, there was no synergistic effect between phosphine and 10–20% O_2 for 72 h fumigation, nevertheless high levels of oxygen can suppress the fire risk of phosphine during fumigation (Bond & Miller 1988; Ohtani *et al*. 1989). Therefore, we consider that co-fumigation of CO_2 or N_2 can be one of the potential methods for controlling the phosphine-resistant *Sitophilus* weevils in the imported rice warehouses. Besides, even if the weevils survive under co-fumigation condition, their reproductive rate may decrease after fumigation that in turn reduces the required fumigation frequency and the fumigation costs (Manivannan *et al*. 2016). The application potential of co-fumigation of insecticides with gases for pest control in the imported rice warehouses, and their control efficacy deserve further study.

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REFERENCES

Anonymous. 1975. Recommended methods for the detection and measurement of resistance of agricultural pests to pesticides.Tentative method for adults of some major pest species of stored cereals, with methyl bromide and phosphine- FAO Method No. 16. FAO Plant Prot. Bull. 23:12–25.

Athié, I., R. A. R. Gomes, S. Bolonhezi, S. R. T. Valentini, and M. F. P. M. De Castro. 1998. Effects of carbon dioxide and phosphine mixtures on resistant populations of stored-grain insects. J. Stored Prod. Res. 34:27–32. doi:10.1016/S0022-474X(97)00026-X

Blomberg, M. R. A. and P. E. M. Siegbahn. 2014. Proton pumping in cytochrome c oxidase: Energetic requirements and the role of two proton channels. Biochim. Biophys Acta. Bioenerg. 1837:1165–1177. doi:10.1016/j.bbabio.2014.01.002

Bond, E. J. and D. M. Miller. 1988. A new technique for measuring the combustibility of gases at reduced pressures and its application to the fumigant phosphine. J. Stored. Prod. Res. 24:225–228. doi:10.1016/0022-474X(88)90023-9

Boopathy, B., A. Rajan, and M. Radhakrishnan. 2022. Ozone: An alternative fumigant in controlling the stored product insects and pests: A status report. Ozone. Sci. Eng. 44:79–95. doi:10.1080/01919512.2021.1933899

Chaudhry, M. Q. and N. R. Price. 1992. Comparison of the oxidant damage induced by phosphine and the uptake and tracheal exchange of 32P-radiolabelled phosphine in the susceptible and resistant strains of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae). Pestic. Biochem. Physiol. 42:167–179. doi:10.1016/0048-3575(92)90063-6

Chen, Z., D. Schlipalius, G. Opit, B. Subramanyam, and T. W. Phillips. 2015. Diagnostic molecular markers for phosphine resistance in U.S. populations of *Tribolium castaneum* and *Rhyzopertha dominica*. PLoS ONE 10:e0121343. doi:10.1371/journal.pone.0121343

Constantin, M., R. Jagadeesan, K. Chandra, P. Ebert, and M. K. Nayak. 2020. Synergism between phosphine (PH_3) and carbon dioxide (CO_2): Implications for managing PH_3 resistance in rusty grain beetle (Laemophloeidae: Coleoptera). J. Econ. Entomol. 113:1999–2006. doi:10.1093/jee/toaa081

Kashi, K. P. and E. J. Bond. 1975. The toxic action of phosphine: Role of carbon dioxide on the toxicity of phosphine to *Sitophilus granarius* (L.) and *Tribolium confusum* DuVal. J. Stored Prod. Res. 11:9–15. doi:10.1016/0022-474X(75)90056-9

Lambkin, T. A. 2001. The toxicity of phosphine in combination with 5% and 10% carbon dioxide against all stages of a strongly phosphine-resistant strain of *Rhyzopertha dominica* (Coleoptera: Bostrychidae). p.617–623. *in*: Proceedings of the International Conference on Controlled Atmosphere and Fumigation in Stored Products. October 29–November 3, 2000. Fresno, CA. Executive Printing Services, Clovis, CA.

Levy-de la Torre, V. A., L. Gómez-García, J. Borboa-Flores, F. J. Wong-Corral, F. J. Cinco-Moroyoqui, and O. Martínez-Cruz. 2018. Actividad citocromo c oxidasa y atpasa de *Rhyzopertha dominica* bajo el efecto de las atmósferas modificadas. Biotecnia 20:79–84. doi:10.18633/biotecnia.v20i2.603

Liu, Y. B. 2011. Oxygen enhances phosphine toxicity for postharvest pest control. J. Econ. Entomol. 104:1455–1461. doi:10.1603/ec10351

Manivannan, S., G. E. Koshy, and S. A. Patil. 2016. Response of phosphine-resistant mixed-age cultures of lesser grain borer, *Rhyzopertha dominica* (F.) to different phosphine-carbon dioxide mixtures. J. Stored Prod. Res. 69:175–178. doi:10.1016/j.jspr.2016.08.005

McGovran, E. R. 1932. The effect of some gases on the tracheal ventilation of grasshoppers. J. Econ. Entomol. 25:271–276. doi:10.1093/jee/25.2.271

Mitcham, E., T. Martin, and S. Zhou. 2006. The mode of action of insecticidal controlled atmospheres. Bull. Entom. Res. 96:213–222. doi:10.1079/ber2006424

Nayak, M. K. and P. J. Collins. 2008. Influence of concentration, temperature and humidity on the toxicity of phosphine to the strongly phosphine-resistant psocid *Liposcelis bostrychophila* Badonnel (Psocoptera: Liposcelididae). Pest Manag. Sci. 64:971–976. doi:10.1002/ps.1586

Ohtani, H., S. Horiguchi, Y. Urano, M. Iwasaka, K. Tokuhashi, and S. Kondo. 1989. Flammability limits of arsine and phosphine. Combust. Flame 76:307–310. doi:10.1016/0010-2180(89)90113-2

Oppert, B., R. N. C. Guedes, M. J. Aikins, L. Perkin, Z. Chen, T. W. Phillips, … F. Arthur. 2015. Genes related to mitochondrial functions are differentially expressed in phosphine-resistant and -susceptible *Tribolium castaneum*. BMC Genom. 16:968. doi:10.1186/s12864-015-2121-0

Pimentel, M. A. G., L. R. D'A. Faroni, R. N. C. Guedes, A. H. Sousa, and M. R. Tótola. 2009. Phosphine resis-

tance in Brazilian populations of *Sitophilus zeamais* motschulsky (Coleoptera: Curculionidae). J. Stored Prod. Res. 45:71–74. doi:10.1016/j.jspr.2008.09.001

Pimentel, M. A. G., L. R. D'A. Faroni, M. R. Tótola, and R. N. C. Guedes. 2007. Phosphine resistance, respiration rate and fitness consequences in stored-product insects. Pest Manag. Sci. 63:876–881. doi:10.1002/ps.1416

Pratt, S. J. 2003. A new measure of uptake: Desorption of unreacted phosphine from susceptible and resistant strains of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). J. Stored Prod. Res. 39:507–520. doi:10.1016/S0022-474X(02)00057-7

Price, N. R. 1984. Active exclusion of phosphine as a mechanism of resistance in *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae). J. Stored Prod. Res. 20:163–168. doi:10.1016/0022-474X(84)90025-0

Rajendran, S. 1990. The toxicity of phosphine, methyl bromide, 1, 1, 1-trichloroethane and carbon dioxide alone and as mixtures to the pupae of red flour beetle, *Tribolium castaneum* herbst. Pestic. Sci. 29:75–83. doi:10.1002/ps.2780290110

Rajendran, S. and M. Muthu. 1989. The toxic action of phosphine in combination with some alkyl halide fumigants and carbon dioxide against the eggs of *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae). J. Stored Prod. Res. 25:225–230. doi:10.1016/0022-474X(89)90028-3

Ren, Y. L., I. G. O'Brien, and C. P. Whittle. 1994. Studies on the effect of carbon dioxide in insect treatment with phosphine. p.173–177. *in*: Proceedings of the 6th International Working Conference on Stored Product Protection. April 17–23, 1994. Canberra, Australia. CAB International. Wallingford, UK.

Sakka, M. K., F. Gatzali, V. T. Karathanos, and C. G. Athanassiou. 2020. Effect of nitrogen on phosphine-susceptible and -resistant populations of stored product insects. Insects 11:885. doi:10.3390/insects11120885

Schlipalius, D. I., N. Valmas, A. G. Tuck, R. Jagadeesan, L. Ma, R. Kaur, … P. R. Ebert. 2012. A core metabolic enzyme mediates resistance to phosphine gas. Science 338:807–810. doi:10.1126/science.1224951

Valizadegan, O., A. A. Pourmirza, and M. H. Safaralizadeh. 2012. The impact of carbon dioxide in stored-product insect treatment with phosphine. Afr. J. Biotechnol. 11:6377–6382. doi:10.5897/AJB10.1971

Wang, D., J. Hou, Y. Huang, and J. Lyu. 2020. Influence of low temperature on lethal time extension for different life stages of *Cryptolestes ferrugineus* (Stephens) with strong resistance to phosphine fumigation. Grain Oil Sci. Technol. 3:25–28.

Winks, R. G. 1985. The toxicity of phosphine to adults of *Tribolium castaneum* (Herbst): Phosphine-induced narcosis. J. Stored Prod. Res. 21:25–29. doi:10.1016/0022-474X(85)90056-6

Wong-Corral, F. J., C. Castañé, and J. Riudavets. 2013. Lethal effects of CO_2-modified atmospheres for the control of three Bruchidae species. J. Stored Prod. Res. 55:62–67. doi:10.1016/j.jspr.2013.08.005

Yang, J., J. S. Park, H. Lee, M. Kwon, G. H. Kim, and J. Kim. 2018. Identification of a phosphine resistance mechanism in *Rhyzopertha dominica* based on transcriptome analysis. J. Asia Pac. Entomol. 21:1450–1456. doi:10.1016/j.aspen.2018.11.012

Yao, M. C., T. C. Wang, W. B. Feng, and C. Y. Lee. 2022. Phosphine Susceptibility in *Sitophilus oryzae* and *Sitophilus zeamais* (Coleoptera: Dryophthoridae) Strains from Imported Brown Rice Warehouses. Formosan Entomol. 42:1–10. (in Chinese with English abstract) doi:10.6662/TESFE.202202_42(1).001

Zuryn, S., J. Kuang, and P. Ebert. 2008. Mitochondrial modulation of phosphine toxicity and resistance in *Caenorhabditis elegans*. Toxicol. Sci. 102:179–186. doi:10.1093/toxsci/kfm278

磷化氫添加氣體對於米象及玉米象 (鞘翅目：椰象鼻蟲科) 之毒性協力效應

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摘要

馮文斌、李啟陽、王泰權、姚美吉。2024。磷化氫添加氣體對於米象及玉米象 (鞘翅目：椰象鼻蟲科) 之毒性協力效應。台灣農業研究 73(1):1–10。

米象屬昆蟲 (*Sitophilus* spp.) 為臺灣進口米倉庫中最嚴重的積穀害蟲，在臺灣已發現對磷化氫產生抗藥性，為克服磷化氫燻蒸對米象屬害蟲防治效果的下降，額外添加氣體與磷化氫共同燻蒸為當前國際最關注的方法。在本研究中，我們評估額外添加 10–20% 二氧化碳、氧氣或氮氣與磷化氫共同燻蒸對米象屬甲蟲之致死效果的提升，我們發現燻蒸 20 h，磷化氫與三種氣體對於抗藥性米象不會產生任何協力作用，然而將燻蒸時間延長至 72 h，添加 10–20% 二氧化碳與氮氣即有助於提升磷化氫對於後壁品系米象之致死效果，其 LC_{50} 從 13.8 μg L^{-1} 降至 2.9–11.0 μg L^{-1}，因此我們認為在磷化氫燻蒸時添加二氧化碳或氮氣，具有提升磷化氫對於進口米倉庫內磷化氫抗藥性積穀害蟲的致死效果。

關鍵詞：米象類、磷化氫、二氧化碳、氧氣、氮氣。

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Research Article

The Newly Recorded Genus *Nipponaetes* Uchida (Hymenoptera: Ichneumonidae: Phygadeuontinae) from Taiwan Based on Redescriptions of Two Species, with Notes on Their Morphological Variations

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Abstract

Chen, H. P. and S. F. Shiao. 2024. The newly recorded genus *Nipponaetes* Uchida (Hymenoptera: Ichneumonidae: Phygadeuontinae) from Taiwan based on redescriptions of two species, with notes on their morphological variations. J. Taiwan Agric. Res. 73(1):11–23.

The genus *Nipponaetes* Uchida, 1933 was first reported from Taiwan, including two species: *N. haeussleri* (Uchida, 1933) and *N. striatus* Momoi, 1970. They were redescribed mainly based on the Taiwanese specimens, with special notes on the variations of the sculpture of metasomal tergite II. The species boundary between both species was also discussed based on extensive morphological and comparative study.

Key words: Redescription, New records, Ichneumonidae, Taxonomy, Taiwan.

INTRODUCTION

Nipponaetes Uchida, 1933 is composed of five described species, *N. haeussleri* (Uchida, 1933), *N. inelegans* (Seyrig, 1952), *N. fessus* (Townes, 1958), *N. striatus* Momoi, 1970, and *N. hansoni* (Gauld, 1997) and distributed pantropically, spanning the Oriental, Afrotropical, Neotropical, and Oceanic regions (Yu *et al*. 2016). The phylogenetic position and generic limits of *Nipponaetes* were previously discussed by Broad *et al*. (2004). By using morphological and molecular (28S D2–D3 ribosomal DNA) evidence, a neotropical tryphonine genus *Zurquilla* Gauld, 1997 was synonymized with *Nipponaetes*, and the suprageneric placement of *Nipponaetes* within Phygadeuotinae (tribe Phygadeuontini in subfamily Cryptinae *sensu* Broad *et al*. (2004)) rather than Tryphoninae was supported. Previous records indicated that *Nipponaetes* is associated with rice field agroecosystems (Momoi 1966; He 1984). It was reported to attack a wide range of hosts, including the pupae of Oriental fruit moth *Grapholitha molesta* (Busck, 1916) (Uchida 1933), cocoons of braconid wasp *Cotesia ruficrus* (Haliday, 1834) (He 1984; He *et al*. 1996), and egg sacs of Arachnids (Broad *et al*. 2004).

By examining the specimens obtained from a rice field arthropods biodiversity survey in Taiwan and specimens preserved in different museums, *Nipponaetes* Uchida was confirmed as a newly recorded genus in Taiwan, and *N. haeussleri* (Uchida, 1933) and *N. striatus* Momoi, 1970 were recorded for the first time in Taiwan. Two species were redescribed based on Taiwanese specimens. Morphologi-

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cal variations and species boundaries of two species were also discussed based on detailed morphological examinations and multivariate analysis of the measurements.

MATERIALS AND METHODS

Morphological examination

Morphological terminology followed Broad *et al*. (2018), and the measurements followed Konishi (1985) in this study. Description of the cuticular microsculpture followed Eady (1968). The abbreviations and newly proposed measurements used in this study are listed below: post ocellus diameter (**OD**); posterio-ocellar line (**POL**); ocello-ocular line (**OOL**); basal width of areola (**ABW**); medial width of areola, the width of areola at the middle position of anterior transverse carina (costula) (**AMW**); apical width of areola (**AAW**); length of areola (**AL**). The materials examined in this study were deposited in the following institutes:

TARI: Taiwan Agricultural Research Institute, Taichung, Taiwan.

SEHU: The Laboratory of Systematic Entomology, The Hokkaido University Museum, Sapporo, Japan.

MNHAH: Museum of Nature and Human Activities, Sanda, Hyogo, Japan.

BM: Bishop Museum, Honolulu, Hawaii, USA.

Specimens were examined and measured by the microscope LEICA S8AP0 with an electronic micrometer (TEKFAR Inc., Taichung, Taiwan). Photographs were taken by LEICA DMC5400 adjacent to LEICA Z16 APO with auto-stacking system LAS V4.13 (Leica Microsystems, Wetzlar, Germany). All figures were edited and arranged into figure plates by Adobe Illustrator CC and Photoshop CC (Adobe Systems Inc., San Jose, CA, USA). The Latin term *ibidem*, meaning “same as previous except as follows”, was used for compressing the locality information in the materials examined section.

Measurements and statistical analysis

Descriptive statistics was performed by Microsoft Excel (Microsoft, Redmond, WA, USA). Principal component analysis (PCA) and biplots of first and second principal components (PC1 and PC2) of 21 variates (including OD, head width/length, POL/OD, OOL/OD, face width/height, clypeus width/height, malar space length/basal mandibular width, mesuscutum length/width, scutellum length/width, fore wing distance between Rs&M and cu-a/ cu-a length, tergite I length/ apical width, tergite II length/ apical width, tergite II basal width/apical width, hind femur length/width, first flagellomere length/width, second flagellomere length/width, hind basitarsus length/second tarsomere length, ABW/AL, AMW/AL, AAW/AL, ABW/AMW) from 30 female *Nipponaetes* specimens were performed in R 4.2.1 (R Core Team 2022).

RESULTS

Taxonomy

Genus *Nipponaetes* Uchida, 1933 [角臉姬蜂屬]

Nipponaetes Uchida, 1933:160. Type species: *Hemiteles* (*Nipponaetes*) *haeussleri* Uchida, 1933, by original designation.

Potia Seyrig, 1952:36. Type species: *Potia inelegans* Seyrig, 1952, by original designation. Synonymized with *Nipponaetes* by Townes *et al*. 1965:136.

Thalops Townes, 1958:57. Type species: *Thalops fessus* Townes, 1958, by original designation. Synonymized with *Potia* by Townes *et al*. 1961:124.

Zurquilla Gauld, 1997:404. Type species: *Zurquilla hansoni* Gauld, 1997, by original designation. Synonymized with *Nipponaetes* by Broad *et al*. 2004:653.

Diagnosis.

This genus can be separated from other phygadeuontine genera by the combinations of

the following characteristics: face usually with compressed convexity medially; clypeus truncate; notauli extend after half of mesoscutum and joining together posteriorly; scutellum with lateral carina; propodeum without distinct apophyses; postpectal carina complete; lateral longitudinal carina of propodeum present before spiracle; fore wing 2m-cu fully developed with one bulla; hind wing nervellus distinctly inclivous and intercepted; tergites II and III separated and unspecialized.

Key to Taiwanese species of *Nipponaetes*

(1) Malar space with single yellow marking (Fig. 1D); hind coxa reddish brown (Fig. 1A); hind tibia and femur with black or blackish brown marking distinct (Fig. 1A); convexity of middle face triangular (Fig. 1D); metasomal tergite II with granulated type (Fig. 1E)... *N. haeussleri* (Uchida, 1933).

(2) Malar space black without single yellow

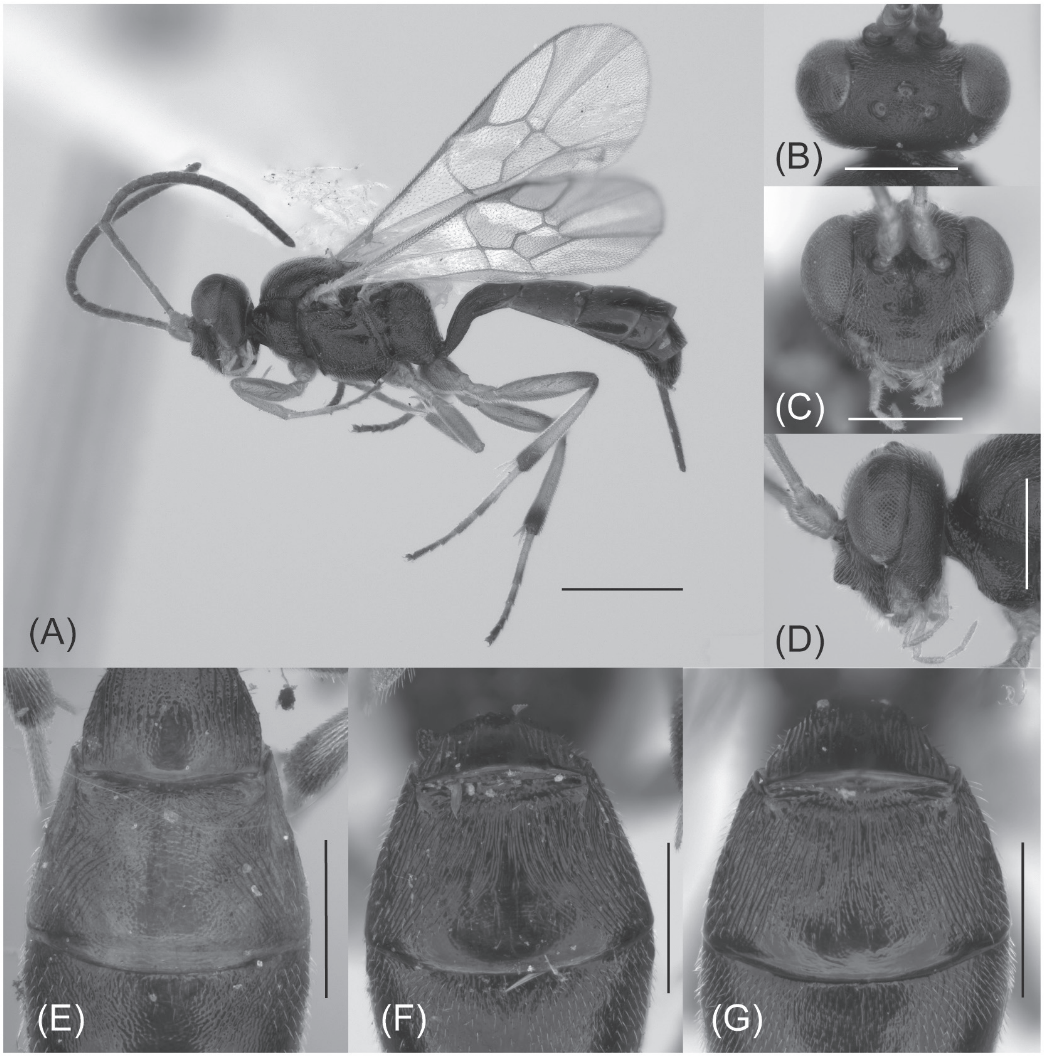

Fig. 1. *Nipponaetes haeussleri* (Uchida, 1933), female (TARI). (A) lateral habitus; (B) head in dorsal view; (C) head in anterior view; (D) head in lateral view; (E) metasomal tergite II, Type I; (F) ditto, Type II; (G) ditto, Type III. Scale bars: (A) 1 mm; (B)–(G) 0.5 mm.

marking (Fig. 2D); hind coxa blackish brown (Fig. 2A); hind tibia and femur with blackish brown marking gradually faded (Fig. 2A); convexity of middle face short and blunt (Fig. 2D); metasomal tergite II not granulated.. *N. striatus* Momoi, 1970.

Nipponaetes haeussleri (Uchida, 1933) 黑角臉姬蜂

Hemiteles (*Nipponaetes*) *haeussleri* Uchida, 1933:159.

Nipponaetes haeussleri–Townes, 1957: 113.

Diagnosis.

This species can be separated from other Asian congeners, *N. fessus* (Townes, 1958) and *N. striatus* Momoi, 1970, by the combination of the following characters: malar space with a yellow marking; fore wing cu-a slant outward; hind coxa reddish brown; metasomal tergite II with granulated type.

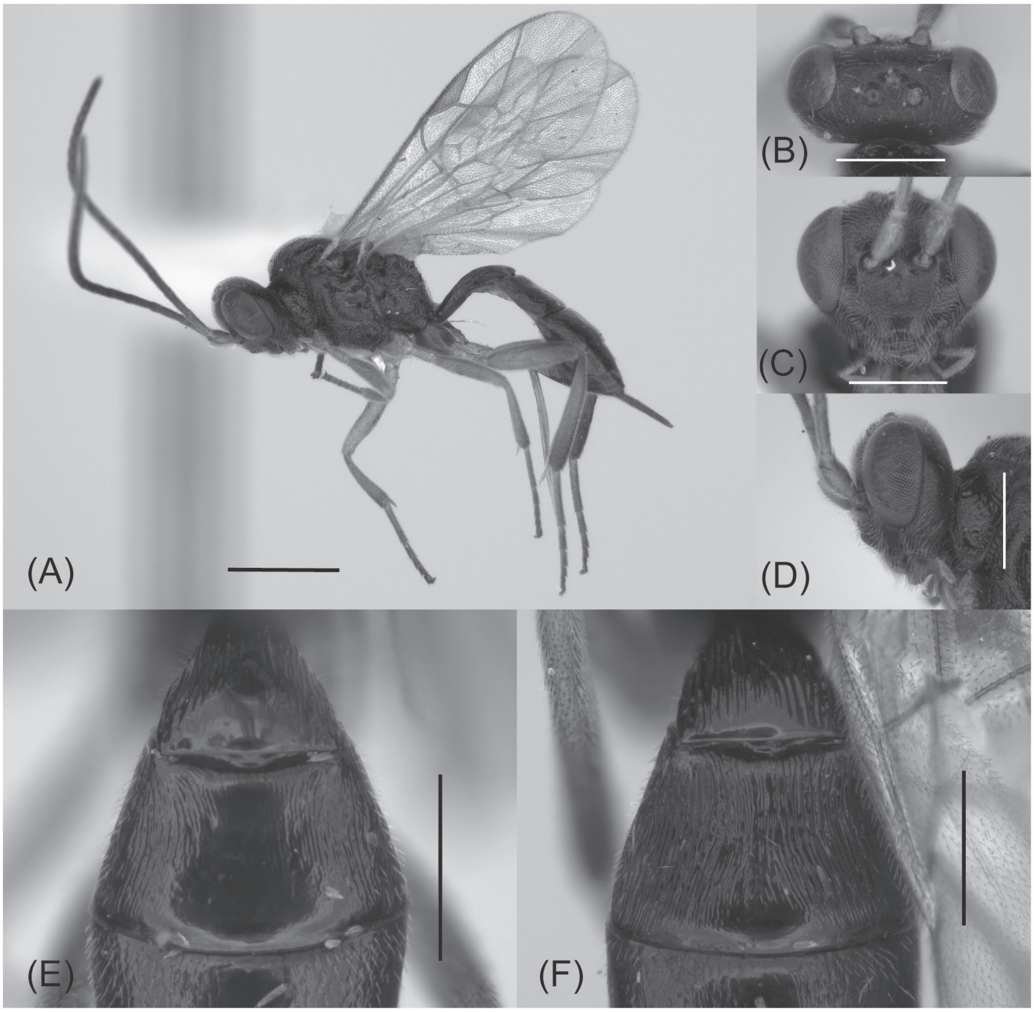

Fig. 2. *Nipponaetes striatus* Momoi, 1970, female (TARI). (A) lateral habitus; (B) head in dorsal view; (C) head in anterior view; (D) head in lateral view; (E) metasomal tergite II, Type I; (F) ditto, Type II. Scale bars: (A) 1 mm; (B)–(F) 0.5 mm.

Materials examined.

Type material. Holotype: 1♀ (SEHU), "Suigen (= Su-Won), Keikiko, Chosen (= Korea)", 30.X.1932, G. J. Haessler leg., Reared from pupae of *G. molesta* (*Grapholitha molesta*). **Non-type materials.** 1♂ (TARI, NP16), "C. Taiwan (= Central Taiwan), Taichung (TAEs)", 11.V.1976, K. S. Lin leg., Rice field; 1♀ (TARI, NP08), "C. Taiwan, Wangfeng Hill, Taichung Hsien (= Taichung county)", 30.XII.1982, K. C. Chou, S. P. Huang leg.; 1♂ (TARI, NP15), "C. Taiwan, Wangfeng, Taichung Hsien", 31.XII.1979, K. S. Lin leg.; 1♀ (TARI, NP35), "N. Taiwan (= Northern Taiwan), Sintien [新店]", 20.XII.1968, K. H. Chang leg.; 1♀ (TARI, NP05), "E. S. Taiwan (= Eastern South Taiwan), Chihpen [知本], Taitung Hsien (= Taitung County)", 17–18.XI.1982, L. Y. Chou, K. C. Chou leg.; 1♂, 2♀♀ (TARI, NP23–25), "Formosa, Kagi (= Chiayi)", M. Kato leg., "蜘蛛巣寄生 [parasiting the nest of spider]"; 1♀ (TARI, NP34), "Kueishan, Taiwan", 1.III.1963, S. C. Chiu leg.; 2♀♀ (TARI, NP12, 29), "N. Taiwan, Taipei", 26.XI.1968, K. H. Chang leg.; 5♀♀ (TARI, NP09–11, 13, 21), "S. Taiwan (= Southern Taiwan), Chishan [旗山], Pingtung Hsien (= Pingtung County)", 25.III.1982, K. C. Chou, C. C. Pan leg.; 4♀♀ (TARI, NP01, 03, 04, 19), "S. Taiwan, Lanyu [= Orchid Island; 蘭嶼], Taitung Hsien", K. S. Lin, K. C. Chou, S. C. Lin, C. C. Pan leg.; 3♂♂ (TARI, NP07, 18–20), *ibidem*, 13–18.IV.1981, K. S. Lin, L. Y. Chou, T. Lin, S. C. Lin leg.; 2♀♀ (TARI, NP02, 06), "S. Taiwan, Shantimen [三地門], Pingtung Hsien", 24.III.1982, K. C. Chou, C. C. Pan leg.; 1♂, 1♀ (TARI, NP14, 36), *ibidem*, 1–5.III.1982; 1♂ (TARI, NP22), "Taihoku", 16.XI.1920, J. Sonan leg.; 1♂ (TARI, NP32), "Taiwan, Kuanhsi [關西]", 13.XII.1968, Unknown collector, Malaise trap; 1♂ (TARI, NP28), "Taiwan, Sintien", 9.IV.1968, S. H. Lin leg.; 1♀ (TARI, NP30), *ibidem*, 20.XII.1968, K. H. Chang leg.; 1♀ (TARI, NP27), "Taiwan, Taichung, Wangfeng", 24.III.1979, K. S. Lin leg.; 1♀ (TARI, NP26), "Taiwan, Taipei", 6.VIII.1960, K. S. Lin leg., Rice field; 1♀ (TARI, NP31), *ibidem*, 24.XI.1962, H. H. Cheng leg.; 1♀ (TARI, NP33), *ibidem*, 29.VII.1967, K. C. Chou; 1♂ (TARI, NP17), *ibidem*, 15.IV.1963, H. H. Cheng leg.; 1♂ (TARI), "Taiwan, Miaoli County, Yuanli Township, 24.378030 N, 120.697275 E, LC-1", 1.XI.2019, C. L. Huang leg., Rice field; 1♂ (TARI), "Taiwan, Miaoli County, Yuanli Township, 24.368548 N, 120.705008 E, LO-3", 26.VI.2019, C. L. Huang leg.

Redescription.

The redescription was based on Taiwanese specimens (25 females, 12 males).

Female. Head granulated, 1.57–2.13 (1.85 ± 0.17) times as wide as long; face polished, densely punctate with setae, 1.58–2.45 (1.99 ± 0.20) times as wide as height, with single compressed convexity medially, triangular in lateral view; eyes bare; malar space 1.08–2.00 (1.44 ± 0.21) times of basal mandibular width; clypeus polished, sparsely punctate with setae, 1.67–2.88 (2.11 ± 0.33) times as wide as height, apically truncate, convex medially in lateral view, apical margin with long setae; mandible bidentate, with upper tooth longer than lower tooth; occipital carina joined with hypostomal carina behind mandible base; OD 0.05–0.08 (0.06 ± 0.01) mm; POL/OD = 1.38–3.00 (2.15 ± 0.43); OOL/OD = 1.00–2.00 (1.46 ± 0.32); flagellomeres 20; first flagellomere 4.00–6.25 (4.91 ± 0.59) times as long as wide, 0.86–1.22 (1.04 ± 0.09) times as long as second; second flagellomere 4.00–5.80 (4.72 ± 0.44) times as long as wide.

Mesosoma granulated; pronotum polished, with short transverse carina at upper- and lower-posterior corners; epomia present; mesuscutum 0.87–1.08 (0.95 ± 0.06) times as long as wide; notauli distinct, extend after 0.5 of mesoscutum and joining together posteriorly; scutellum polished, granulated or rugose, 0.63–1.14 (0.87 ± 0.15) times as long as wide, with lateral carina extends to its apex; mesopleurum smooth at ventral posterior corner, with weakly and oblique striate medially; speculum polished and smooth; epicnemial carina strong, extend to about 0.6 anterior

height of mesopleurum; sternaulus extend above 0.7 lengths of mesopleurum; propodeum rugoso-punctate; propodeal spiracle circular; all carinae complete and strong; ABW/AL = 0.27–0.73 (0.45 ± 0.12); AMW/AL = 0.80–1.50 (1.13 ± 0.18); AAW/AL = 0.60–1.25 (0.86 ± 0.15); ABW/AMW = 0.27–0.56 (0.40 ± 0.07).

Fore wing length 2.16–3.11 (2.81 ± 0.21) mm; cu-a slant outward, distad Rs&M 0.14–0.33 (0.24 ± 0.06) by its length; areolet absent, 2r-m length subequal to first abscissa (1/M); 2m-cu slant outward with one bulla; hind wing nervellus inclivous, intercepted at about lower 0.2.

Legs with coxa polished and punctate; tibial spurs equal length in mid legs, outer slightly longer than inner in hind legs; hind femur 4.00–5.69 (4.62 ± 0.48) times as long as wide; hind basitarsus 1.89–2.88 (2.32 ± 0.23) times as long as second; tarsal claws simple.

Metasoma with tergite I dorsally curved in lateral view, 0.96–1.69 (1.35 ± 0.20) times as long as apical width, highly variable in sculpture, ranging from granulated to smooth; petiole with longitudinal striae at middle area, postpetiole with longitudinal striae at lateral area; glymma absent; latero-median carina and dorsolateral carina present; tergite II 0.49–0.71 (0.61 ± 0.05) times as long as apical width, basal width 0.64–0.76 (0.69 ± 0.03) times as wide as apical width, sculpture highly variable, ranging from granulated to smooth, with weak to strong longitudinal striae at basal 0.7–0.9, straight basally and oblique laterally, or oblique laterally that forming a triangle area, or straight; thyridium present; tergite III granulate or striate at basal 0.5, smooth at apical 0.5; tergites after IV polished and smooth; ovipositor sheath straight, slightly tapered apically; ovipositor straight, without nodus, lower valve longer than upper valve, with proximal tooth apically.

Colors: head black; scape, pedicel, and basal 3–5 flagellomeres reddish brown, another part black or blackish brown; malar space with single triangular yellow marking; mandible yellowish brown, reddish brown at apex; maxillary and labial palps yellow; mesosoma black except tegula reddish brown or yellow; legs yellowish brown, except coxae reddish brown, apical part of hind femora, basal and apical part of hind tibia distinctly black or blackish brown, and tarsus except basal part of hind basitarsus blackish brown; wing hyaline; wing veins pale brown; metasomal tergites black, blackish brown tinged with reddish brown, or reddish brown; ovipositor sheath blackish brown; ovipositor yellowish brown.

Male. Male coloration and body structures were mostly similar to females except the following measurements: head 1.68–2.09 (1.88 ± 0.14) times as wide as long; face 1.57–2.05 (1.83 ± 0.16) times as wide as long; clypeus 1.67–2.88 (2.08 ± 0.35) times as wide as long; malar space 1.09–1.67 (1.41 ± 0.18) as long as basal mandibular width; OD = 0.04–0.08 (0.06 ± 0.01) mm; POL/OD = 1.71–3.00 (2.33 ± 0.43); OOL/OD = 1.00–2.00 (1.52 ± 0.30); first flagellomere 3.33–5.50 (4.04 ± 0.66) times as long as wide, 0.69–0.85 (0.74 ± 0.04) times as long as second; second flagellomere 2.57–4.75 (3.18 ± 0.57) times as long as wide; mesoscutum 0.88–1.03 (0.95 ± 0.05) times as long as wide; scutellum 0.71–1.03 (0.85 ± 0.11) times as long as wide; fore wing length 2.23–3.00 (2.69 ± 0.23) mm; cu-a distad Rs&M 0.14–0.33 (0.25 ± 0.05) by its length; basitarsus 2.00–3.38 (2.37 ± 0.39) times as long as second tarsomere; BW/AL = 0.43–0.73 (0.56 ± 0.11); AMW/AL = 0.85–1.55 (1.16 ± 0.18); AAW/AL = 0.73–1.18 (0.85 ± 0.12); ABW/AMW = 0.40–0.62 (0.49 ± 0.07).

Distribution. China (Guangdong, Hubei, Jiangsu, Zhejiang) (He 1984; He *et al.* 1996; He *et al.* 2004), India (Momoi 1966), Japan (Honshu, Kyushu, Amamioshima Is., Okinawajima Is.) (Momoi 1970; Watanabe 2021), Korea (Uchida 1933), Philippine (Luzon Is.) (Momoi 1966), Thailand (Broad *et al.* 2004), new to Taiwan (Taipei, Hsinchu, Miaoli, Taichung, Chiayi, Pingtung, Taitung, Lanyu Is.).

Bionomics. Hosts: *Grapholitha molesta* (Busck, 1916) (Uchida, 1933); *Cotesia ruficrus* (Haliday, 1834) (He 1984; He *et al.* 1996); egg sacs

of Arachnids (Broad *et al*. 2004; this study). This species was reported to be associated with rice field agroecosystem (Momoi 1966).

Remarks. The sculpture of metasomal tergite II was observed to be highly variable in this species. It was summarized to three types: **Type I**, same as holotype, granulated with weak and dense longitudinal striae at basal 0.7–0.9, straight basally and oblique laterally (*n* = 25) (Fig. 1E); **Type II**, polished and smooth, with weak longitudinal striae at basal 0.7, oblique laterally and forming a smooth triangle area apically (*n* = 4) (Fig. 1F) and **Type III**, polished and smooth, with strong and straight longitudinal striae at basal 0.7 (*n* = 8) (Fig. 1G).

High variation of measurements and metasomal tergite II sculptures might indicate hidden diversity within this species. The measurements of samples from different metasomal tergite II types are summarized in Table 1.

Chinese vernacular name. The current Chinese vernacular name of *N. haeussleri* was mentioned in He (1984) and He *et al*. (1996), representing both the black body color and transliteration of the eponymous specific name.

Nipponaetes striatus Momoi, 1970 條背角臉姬蜂

Nipponaetes striatus Momoi, 1970:346.

Table 1. Measurements of different tergite II types in Taiwanese *Nipponaetes* females.

Species	*N. haeussleri*			*N. striatus*	
	Type I	Type II	Type III	Type I	Type II
Tergite type	*n* = 17	*n* = 4	*n* = 4	*n* = 6	*n* = 1
OD (mm)	0.05–0.07	0.07	0.06–0.08	0.07–0.08	0.08
OOL/OD	1.14–2.20	1.00–1.57	1.00–1.50	1.00–1.43	1.00
POL/OD	1.71–2.80	1.57–2.57	1.38–3.00	1.25–1.71	1.38
Head width/length	1.57–2.08	1.76–2.13	1.70–1.95	1.78–2.05	1.84
Face width/height	1.58–2.20	1.82–2.28	1.95–2.45	2.00–2.50	2.00
Clypeus width/height	1.67–2.88	1.85–2.42	1.80–2.08	1.82–2.50	2.31
Malar space/mandible width	1.08–2.00	1.17–1.78	1.36–1.42	1.33–1.80	1.33
First flagellomere length/width	4.17–6.25	4.40–5.00	4.00–5.80	3.50–5.00	5.00
Second flagellomere length/width	4.00–5.80	4.00–5.40	4.50–5.60	4.40–5.75	4.50
First flagellomere length/second	0.86–1.22	0.93–1.14	0.89–1.08	0.91–1.11	1.11
Mesoscutum length/width	0.87–1.08	0.90–0.98	0.92–1.05	0.86–1.05	0.96
Scutellum length/width	0.70–1.14	0.74–0.89	0.63–0.88	0.71–0.96	0.83
Fore wing length (mm)	2.16–2.98	2.85–3.11	2.85–3.07	2.52–3.00	3.00
Distance between Rs&M and cu-a/cu-a length	0.14–0.33	0.17–0.29	0.14–0.27	0.18–0.33	0.18
ABW/AL	0.27–0.64	0.42–0.73	0.41–0.64	0.40–0.75	0.75
AMW/AL	0.80–1.42	1.08–1.50	1.06–1.36	1.00–1.25	1.25
AAW/AL	0.60–1.25	0.67–1.09	0.73–0.92	0.73–0.94	0.88
ABW/AMW	0.27–0.56	0.33–0.50	0.39–0.50	0.35–0.60	0.60
Tergite I length/width	0.96–1.69	1.04–1.30	1.15–1.57	1.39–1.83	1.80
Tergite II length/width	0.49–0.71	0.60–0.65	0.54–0.62	0.51–0.75	0.67
Tergite II basal/apical width	0.64–0.76	0.65–0.75	0.65–0.75	0.62–0.70	0.62
Hind femur length/width	4.19–5.69	4.13–5.23	4.00–4.59	3.95–4.93	4.23
Hind basitarsus length/second tarsomere	1.89–2.58	2.20–2.62	2.11–2.88	2.20–2.47	2.43

Diagnosis.

This species can be separated from other Asian congeners by the combination of the following characteristics: malar space without yellow marking; fore wing cu-a slant outward; hind coxa blackish brown or black; metasomal tergite II not granulated.

Materials examined.

Type material. Holotype: 1♂ (BM, Bishop 9140, temporarily deposited in MNHAH), "Kara-yama, Ishigaki Is., Ryukyu Is.", 14–18.III.1964, C. M. Yoshimoto, J. Harrell leg., Malaise Trap. (by Photos). **Non-type materials.** 1♀ (TARI, NP44), "C. Taiwan, Lushan [廬山], 1000 m, Nantou Hsien", 27–31.V.1980, K. S. Lin, L. Y. Chou leg.; 1♀ (TARI, NP43), "C. Taiwan, Tungpu [東埔], 1200m, Nantou Hsien", 5–8.X.1981, T. Lin, W. S. Tang leg.; 1♀ (TARI, NP37), "N. Taiwan, Wufeng [五峰], 400m, Hsinchu Hsien", 14–16.VII.1982, K. C. Chou, C. C. Pan leg.; 1♀ (TARI, NP38), "S. Taiwan, Shantimen, Pingtung Hsien", 31.I–4.II.1983, K. C. Chou, S. P. Huang leg.; 2♀♀ (TARI, NP41–42), *ibidem*, 1–5.III.1982, K. C. Chou, C. C. Pan leg.; 1♂, 1♀ (TARI, NP39–40), "S. Taiwan. Lanyu, Taitung Hsien", 4–9.V.1982, K. S. Lin, K. C. Chou, S. C. Lin, C. C. Pan leg.; 1♀ (TARI, NP45), "東埔 [Dongpu]", 28.XI.1957, F. L. Ye leg.

Redescription.

The redescription was based on Taiwanese specimens (7 females, 2 males).

Female. Head granulated, 1.78–2.05 (1.91 ± 0.11) times as wide as long; face polished, densely punctate with setae, 2.00–2.50 (2.20 ± 0.16) times as wide as height, with single compressed convexity medially, short and blunt in lateral view; eyes bare; malar space 1.33–1.80 (1.50 ± 0.16) times of basal mandibular width; clypeus polished, sparsely punctate with setae, 1.82–2.50 (2.14 ± 0.28) times as wide as height, apically truncate, convex medially in lateral view, apical margin with long setae; mandible bidentate, with upper tooth longer than lower tooth; occipital carina joined with hypostomal carina behind mandible base; OD 0.07–0.08 (0.08 ± 0.005) mm; POL/OD = 1.25–1.71 (1.52 ± 0.16); OOL/OD = 1.00–1.43 (1.21 ± 0.18); flagellomeres 20; first flagellomere 3.50–5.00 (4.36 ± 0.45) times as long as wide, 0.91–1.11 (0.97 ± 0.07) times as long as second; second flagellomere 4.40–5.75 (4.75 ± 0.47) times as long as wide.

Mesosoma granulated; pronotum polished, with short transverse carina posteriorly; epomia present; mesuscutum 0.86–1.05 (0.94 ± 0.07) times as long as wide; notauli distinct, extend after 0.5 of mesoscutum and joining together posteriorly; scutellum polished, rugose with transverse carina, 0.71–0.96 (0.86 ± 0.08) times as long as wide, with lateral carina extends to its apex; mesopleurum smooth at ventral posterior corner, with weakly and oblique striate medially; speculum polished and smooth; epicnemial carina strong, extend to 0.8 anterior height of mesopleurum; sternaulus extend above 0.7 length of mesopleurum; propodeum rugoso-punctate; propodeal spiracle circular; all carinae complete and strong; ABW/AL = 0.40–0.75 (0.52 ± 0.13); AMW/AL = 1.00–1.25 (1.11 ± 0.08); AAW/AL = 0.73–0.94 (0.86 ± 0.08); ABW/AMW = 0.35–0.60 (0.47 ± 0.09).

Fore wing length 2.52–3.00 (2.71 ± 0.20) mm; cu-a slant outward, distad Rs&M 0.18–0.33 (0.25 ± 0.05) by its length; areolet absent, 2r-m length subequal to first abscissa (1/M); 2m-cu slant outward with 1 bulla; hind wing nervellus inclivous, intercepted at about lower 0.2.

Legs with coxa polished and punctate; tibial spurs equal length in mid and hind legs; hind femur 3.95–4.93 (4.28 ± 0.33) times as long as wide; hind basitarsus 2.20–2.47 (2.34 ± 0.11) times as long as second; tarsal claws simple.

Metasoma with tergite I dorsally curved in lateral view, 1.39–1.83 (1.67 ± 0.15) times as long as apical width, polished and smooth; petiole and postpetiole with longitudinal striae medially; glymma absent; latero-median cari-

na and dorso-lateral carina present; tergite II 0.51–0.75 (0.66 ± 0.08) times as long as apical width, basal width 0.62–0.70 (0.64 ± 0.03) times as wide as apical width, sculpture variable, polished and smooth, with weak to strong longitudinal striae at basal 0.7–0.9, completely straight or oblique laterally; thyridium present; tergite III smooth; tergites after IV polished and smooth; ovipositor sheath straight, slightly tapered apically; ovipositor straight, without nodus, lower valve longer than upper valve, with proximal tooth apically.

Colors: head black; scape, pedicel, and basal 2 flagellomeres reddish brown, another part black or blackish brown; malar space black without pale marking; mandible, maxillary and labial palps reddish brown; mesosoma black except for tegula reddish to blackish brown; legs reddish brown, except fore and mid coxa reddish brown, hind coxae blackish brown, apical part of hind femora, basal and apical part of hind tibia graduated blackish brown, and tarsus except for basal part of hind basitarsus blackish brown; wing hyaline; wing veins pale brown; metasomal tergites black, blackish brown tinged with reddish brown, or reddish brown; ovipositor sheath blackish brown; ovipositor yellowish brown.

Male. Male coloration and body structures were mostly similar to females except for the following measurements: head 1.80–1.97 times as wide as long; face 2.04–2.20 times as wide as long; clypeus 2.25–2.31 times as wide as long; malar space 1.30–1.40 as long as basal mandibular width; OD = 0.07–0.08 mm; POL/OD = 1.50–1.57; OOL/OD = 0.88–1.29; first flagellomere 3.00–3.50 times as long as wide, 1.11 times as long as second; second flagellomere 3.17–3.80 times as long as wide; mesoscutum 0.95–0.96 times as long as wide; scutellum 0.93–0.97 times as long as wide; fore wing length 2.54–2.73 mm; cu-a distad Rs&M 0.23–0.29 by its length; basitarsus 2.35–2.47 times as long as second tarsomere; BW/AL = 0.50–0.57; AMW/AL = 1.08–1.21; AAW/AL = 0.67–0.79; ABW/AMW = 0.46–0.47.

Distribution. Japan (Honshu, Ishigaki Is., Iriomote Is.) (Momoi 1970; Konishi *et al.* 2014), new to Taiwan (Hsinchu, Nantou, Pingtung, Lanyu Is.).

Bionomics. Unknown.

Remarks. The sculpture of metasomal tergite II was observed variable in this species and summarized as two types: **Type I**, same as holotype, polished, smooth with weak and oblique striae laterally (*n* = 6) (Fig. 2E) and **Type II**, polished, with strong and straight striae, smooth middle-posteriorly (*n* = 3) (Fig. 2F). Another type with metasomal tergite II smooth without striae was reported in one Japanese (Honshu) individual (Konishi *et al.* 2014). The measurements of samples from different metasomal tergite II types were summarized in Table 1.

According to the original designation, the holotype deposition should be BM but currently deposited in MNHAH since the type labels of Momoi's types were not attached (Watanabe & Ito 2023). Further confirmation of the deposition of Momoi's type series should be made in the future (Watanabe personal communication).

Chinese vernacular name. This species does not have Chinese vernacular name in the past. The Chinese vernacular name is proposed for the first time according to the etymology of specific name, representing its striate metasomal tergite II.

Multivariate statistical analysis

Morphometric measurements of female *Nipponaetes* form four clusters in the PCA biplot: *N. haeussleri* Type I, II, III, and *N. striatus* Type I (Fig. 3). The 0.68 confidence ellipses of *N. haeussleri* Type II and III are mostly overlapped with those of *N. haeussleri* Type I and *N. striatus* Type I (Fig. 3). The higher scores of the first principal component (PC1: 20.8% of overall variation explained) suggests higher values of OD, ABW/AMW, face width/

length ratio, and ABW/AL, which mainly contributes to the separation of the *N. haeussleri* Type I and *N. striatus* Type I clusters. The second principal component (PC2: 15.6% of overall variation explained) is positively influenced by the ratio of head width/length, AMW/AL and AAW/AL. Principal component analysis also shows that over 90% of the variance in morphometrics can be summarized within PC1 through PC11.

DISCUSSION

Significant morphological variations, particularly on the sculpture of metasomal tergite II and measurements, were observed in both *Nipponaetes* species from Taiwan. Excluding the yellow marking on the malar space and the colors of the hind legs, the metasomal tergite II and measurements of Types II and III in *N. haeussleri* overlap with those of *N. striatus* (Fig. 3; Table 1), making morphological species delimitation of both species unclear. However, the measurements of Type I in both species are the most numerous and separated in the PCA biplot (Fig. 3), allowing for partial differentiation using the OD and POL/OD ratios (Table 1). In contrast, Types II and III in *N. haeussleri* display intermediate characteristics between these clusters.

Since *N. haeussleri* has a broad distribution across East Asia (Yu *et al*. 2016), the expansive distribution range combined with significant morphological variations suggests hidden species diversity within this species that might be uncovered by using integrated taxonomic approaches (e.g., Veijalainen *et al*. 2011; Barão *et al*. 2014; Rougerie *et al*. 2014; Fusu 2017, etc.). If further subdivisions within both species are made, the Type I might be considered typical. It is also noteworthy that the holotype of a Madagascan species, *N. in-*

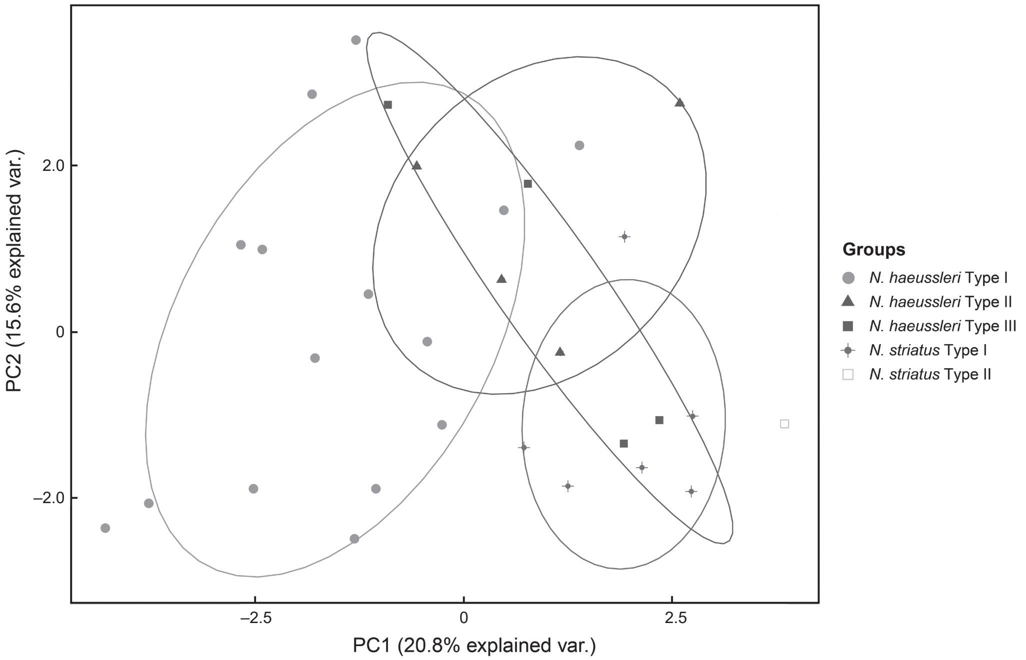

Fig. 3. Principal component (PC) analysis biplot of Taiwanese *Nipponaetes* females. Samples of different metasomal tergite II types were marked and grouped by different colors.

elegans (Seyrig, 1952) (Holotype photos are available at https://science.mnhn.fr/institution/mnhn/collection/ey/item/ey10870?fbclid=I-wAR25OcJooMdvklEmWy23XS4TxLK2i0hje-FOu-wGX5RvSCG0cC1Zmo5RRp-Y), is similar to the Type III of *N. haeussleri*. However, their vast geographical distance suggests they may not be conspecific.

While the morphological species boundaries between *N. haeussleri* and *N. striatus* overlap (Konishi *et al*. 2014; Watanabe 2021; this study), we refrain from making taxonomic treatment in this study due to the limited geographic sampling area and the absence of molecular evidence. Further sampling across a broader geographic range and DNA data are necessary to revise the taxonomy of Asian *Nipponaetes*. The results of the present study fill the distribution gap for *N. haeussleri* and provide the first detailed description of their morphological variations. This contributes to understanding the taxonomy within this group and enhances our knowledge of biodiversity in the rice field agroecosystems in Taiwan.

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REFERENCES

Barão, K. R., G. L. Gonçalves, O. H. H. Mielke, M. R. Kronforst, and G. R. P. Moreira. 2014. Species boundaries in *Philaethria* butterflies: An integrative taxonomic analysis based on genitalia ultrastructure, wing geometric morphometrics, DNA sequences, and amplified fragment length polymorphisms. Zool. J. Linn. Soc. 170:690–709. doi:10.1111/zoj.12118

Broad, G. R., N. M. Laurenne, and D. L. J. Quicke. 2004. The genus *Nipponaetes* (Hymenoptera: Ichneumonidae: Cryptinae) in Costa Rica, with a reassessment of the generic limits. Eur. J. Entomol. 101:651–655. doi:10.14411/eje.2004.088

Broad, G. R., M. R. Shaw, and M. G. Fitton. 2018. Ichneumonid Wasps (Hymenoptera: Ichneumonidae): Their classification and biology. Handbooks for the Identification of British Insects. Vol. 7, Part 12. Royal Entomological Society of London. London, UK. 418 pp.

Eady, R. D. 1968. Some illustrations of microsculpture in the Hymenoptera. Proc. R. Entomol. Soc. Lond. 43:66–72. doi:10.1111/j.1365-3032.1968.tb01029.x

Fusu, L. 2017. An integrative taxonomic study of European *Eupelmus* (*Macroneura*) (Hymenoptera: Chalcidoidea: Eupelmidae), with a molecular and cytogenetic analysis of *Eupelmus* (*Macroneura*) *vesicularis*: Several species hiding under one name for 240 years. Zool. J. Linn. Soc. 181:519–603. doi:10.1093/zoolinnean/zlw021

Gauld, I. D., D. Wahl, K. Bradshaw, P. Hanson, and S. Ward. 1997. The Ichneumonidae of Costa Rica, 2. Mem. Amer. Ent. Inst. 57:1–485.

He, J. H. 1984. A checklist of Ichneumon-flies parasitic on rice pests from China (Hymenoptera: Ichneumonidae). Acta Agric. Univ. Zhejiangensis 10:77–110. (in Chinese with English abstract)

He, J. H., X. X. Chen, J. J. Fan, Q. Li, C. M. Liu, X. M. Lou, ... J. Yao. 2004. Hymenopteran Insect Fauna of Zhejiang. Science Press. Beijing, China. 1373 pp. (in Chinese with English abstract)

He, J. H., X. X. Chen, and Y. Ma. 1996. Hymenoptera: Ichneumonidae. Economic Insect Fauna of China. Science Press. Beijing, China. 697 pp. (in Chinese with English abstract)

Konishi, K. 1985. A revision of the subgenus *Parabates* Foerster of the genus *Netelia* Gray from Japan (Hymenoptera, Ichneumonidae). Kontyû 53:616–624.

Konishi, K., R. Matsumoto, T. Yoshida, and K. Watanabe. 2014. Ichneumonidae and Trigonalidae (Hymenoptera) collected by faunal survey of the Imperial Palace, Tokyo. Mem. Natn. Mus. Nat. Sci., Tokyo

50:485–497. (in Japanese with English abstract)

Momoi, S. 1966. Ichneumonidae (Hymenoptera) collected in paddy fields of the Orient, with descriptions of new species, part 1. Subfamilies Ephialtinae, Gelinae, Banchinae, Anomalinae and Mesochorinae. Mushi 40:1–11.

Momoi, S. 1970. Ichneumonidae (Hymenoptera) of the Ryukyu Archipelago. Pac. Insects 12:327–399.

R Core Team. 2022. R: A language and environment for statistical computing. Version 4.2.1. https://www.r-project.org/ (visit on 5/19/2022)

Rougerie, R., I. J. Kitching, J. Haxaire, S. E. Miller, A. Hausmann, and P. D. N. Hebert. 2014. Australian Sphingidae- DNA barcodes challenge current species boundaries and distributions. PLoS ONE 9:e101108. doi:10.1371/journal.pone.0101108

Seyrig, A. 1952. Les Ichneumonidés de Madagascar. IV. Ichneumonidae Cryptinae. Mem. Acad. Malgache 19:1–213. (in French)

Townes, H. 1957. A review of the generic names proposed for old world Ichneumonids, the types of whose genotypes are in Japan, Formosa or North America. Proc. Entomol. Soc. Wash. 59:100–120.

Townes, H. 1958. Hymenoptera: Ichneumonidae, Stephanidae and Evaniidae. Insects Micronesia 19(2):35–87.

Townes, H., S. Momoi, and M. Townes. 1965. A catalogue and reclassification of the eastern Palearctic Ichneumonidae. Mem. Amer. Ent. Inst. 5:1–661.

Townes, H., M. Townes, and V. K. Gupta. 1961. A catalogue and reclassification of the Indo-Australian Ichneumonidae. Mem. Amer. Ent. Inst. 1:1–522.

Uchida, T. 1933. Über die Schmarotzerhymenopteren von *Grapholitha molesta* Busck in Japan. Insecta Matsumurana 7(4):153–164. (in Germany)

Veijalainen, A., G. R. Broad, N. Wahlberg, J. T. Longino, and I. E. Sääksjärvi. 2011. DNA barcoding and morphology reveal two common species in one: *Pimpla molesta* stat. rev. separated from *P. croceipes* (Hymenoptera, Ichneumonidae). ZooKeys 124:59–70. doi:10.3897/zookeys.124.1780

Watanabe, K. 2021. Taxonomic and zoogeographic study of the Japanese Phygadeuontinae (Hymenoptera, Ichneumonidae), with descriptions of 17 new species. Bull. Kanagawa Pref. Mus. (Nat. Sci.) 50:55–136. doi:10.32225/bkpmnh.2021.50_55

Watanabe, K. and M. Ito. 2023. Revision of the genus *Leptobatopsis* Ashmead, 1900 (Hymenoptera, Ichneumonidae, Banchinae) from Japan, with some taxonomic notes of Asian species. Zootaxa 5339:401–426. doi:10.11646/zootaxa.5339.5.1

Yu, D. S., C. van Achterberg, and K. Horstmann. 2016. Taxapad 2016, Ichneumonoidea 2015. Ottawa, Ontario. http://www.taxapad.com (visit on 10/16/2023, database on flash-drive)

臺灣新紀錄屬── 角臉姬蜂屬 (膜翅目：姬蜂科：粗角姬蜂亞科) 兩物種之重新描述暨其形態變異註記

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摘要

陳玄樸、蕭旭峰。2024。臺灣新紀錄屬── 角臉姬蜂屬 (膜翅目：姬蜂科：粗角姬蜂亞科) 兩物種之重新描述暨其形態變異註記。台灣農業研究 73(1):11–23。

本文首次記錄角臉姬蜂屬 (*Nipponaetes* Uchida, 1933) 於臺灣的分布，包含 2 物種：黑角臉姬蜂 (*N. haeussleri* (Uchida, 1933)) 與條背角臉姬蜂 (*N. striatus* Momoi, 1970)，並依據臺灣產標本對該二物種進行重新描述。本研究著重描述兩物種在後軀第二背板刻紋的形態變異，依據形態檢查與測量值的多變數統計分析，針對兩物種之形態界定進行討論。

關鍵詞：重新描述、新紀錄、姬蜂科、分類學、臺灣。

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研究報告

次氯酸降解試驗及其在滅菌細本山葡萄莖節培植體之應用

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摘要

蕭翌柱、陸明德、林宗俊。2024。次氯酸降解試驗及其在滅菌細本山葡萄莖節培植體之應用。台灣農業研究 73(1):25–36。

次氯酸 (HOCl) 具有強氧化力且能破壞微生物細胞膜通透性達到消毒滅菌的成效，本試驗之主要目的，在於檢測不同光照強度或高溫高壓滅菌後對 HOCl 濃度降解的影響；此外，探討含不同濃度 HOCl 溶液外部消毒處理，對於降低細本山葡萄 (*Vitis thunbergii* Sieb. & Zucc.) 莖節培植體汙染率的影響。結果顯示，將含 HOCl 濃度為 198.3 ± 3.4 mg L^{-1} 的溶液盛裝於深褐色血清瓶，並放置在室內、常溫且避免陽光直射的環境，可維持其穩定性達 5 d 以上；另經高溫高壓滅菌後的 HOCl 含量變化不大。使用 0.6% (w/v) 次氯酸鈉 (NaOCl) 溶液進行細本山葡萄莖節外部消毒 20 min 之培植體汙染率為 82.2 ± 1.6% (對照組)，顯著高於使用 150 與 200 mg L^{-1} HOCl溶液消毒的處理組 (61.1 ± 5.7% & 57.8 ± 4.2%)，且經21 d培養後也未見HOCl影響莖節正常生長。因此，培植體在外部消毒處理時，以 HOCl 取代 NaOCl 的構想具可行性。

關鍵詞：高壓滅菌、光照度、微生物汙染、組織培養。

前言

植物組織培養係選用草本或木本植物的根、莖節、幼葉、頂芽、腋芽、種子及體胚等器官、組織或細胞為標的，經過一系列外部消毒程序後，作為營養繁殖或癒合組織培養之起始材料，此類材料統稱為『培植體』(explant)。若將無菌的『培植體』培養於透光容器內，並提供無機營養鹽類、碳水化合物、維生素、胺基酸或其他有機成分與生長調節物質，在控制適當溫度與光線等環境因子下，促進其生長分化與『再生作用』 (regeneration)，即可誘導發育成為獨立的小苗株。因此，植物組織培養技術也是一種『體外培養技術』 (*in vitro* technology) (Ma & Shii 1992)。自田間或野外採集而來的植物材料，欲成功應用組織培養技術建立無菌培植體之首要步驟，即需依序進行材料的外部清洗、預處理及消毒等程序，避免培植體接種於含糖培養基後，受到細菌或真菌類微生物的汙染；有些學者甚至建議在完成培植體消毒程序後，另在培養基內添加適量的抑菌劑，如植物防腐混合液 (plant preservative mixture; PPM)，以降低培養後期因微生物導致的高汙染率 (Rihan *et al*. 2012)。

一般用於植物組織培養材料外部消毒的殺菌劑種類頗多，較常見的有次氯酸鈉 (NaOCl)、二氯異氰脲酸鈉 (sodium dichloroisocyanurate; NaDCC)、乙醇 (C_2H_6O)、次氯酸鈣 ($Ca(ClO)_2$)、氯化汞 ($HgCl_2$)、硝酸銀 ($AgNO_3$)、過氧化氫 (H_2O_2) 及二氧化氯 (ClO_2) 等 (Morgenthau *et al*. 2012; Mihaljević *et al*. 2013; Silva *et al*. 2015; Boonrattanakij *et al*. 2021)。在前述各種消毒劑中，又以乙醇與 NaOCl 溶液較早被廣泛應用於植物莖節培植體之外部消毒，且對於細菌與真菌類滋生有一定的抑制效

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果，但是，NaOCl 濃度過高或接觸時間太久皆可能造成操作人員嚴重皮膚灼傷，且遇鹼性水質容易形成三鹵化合物，對水生生物毒性甚大 (Emmanuel *et al*. 2004; Small *et al*. 2007; Gomes *et al*. 2010; De Santana *et al*. 2011)；$HgCl_2$ 滅活真菌與抑制微生物滋生的能力，雖優於其他殺菌劑，然後續回收的廢液倘處理不當，極易造成環境汙染與毒害動、植物，其對人體神經、腎臟、呼吸、免疫、皮膚、生殖及發育等方面皆有不良影響 (Hashim *et al*. 2021)。NaDCC 是一種含氯強氧化劑，當預製成白色片劑或溶液時，在室溫下可維持穩定性質 (Shetty & Narasimhan 2021)；使用 NaDCC 仍需注意其用量並避免直接接觸身體皮膚與黏膜等處；不過，進行植物外部消毒與廢液處理時，對於培植體與環境的不良影響相對較小 (Morgenthau *et al*. 2012)，且研究結果顯示，在高濃度 (5,000 mg L^{-1}) 時比市售 NaOCl 殺菌力更佳，若在低濃度 (300 mg L^{-1}) 的情形下，仍能應用於較長時間的幼嫩莖節消毒 (Parkinson *et al*. 1996)。

NaDCC 溶解於水中後，會水解產生次氯酸 (HOCl)，此種 HOCl 即是具備強氧化力且能破壞微生物細胞膜通透性，導致其 DNA、RNA 及 ATP 等遺傳物質洩漏，進而達到滅菌效果的化合物 (Hao *et al*. 2017; Shetty & Narasimhan 2021)，HOCl 也因此可作為研製安全傷口護理敷料的一種添加劑 (Rubinsky *et al*. 2016)。在全世界 COVID-19 疫情流行期間，由添加 HOCl 研製而成的新型噴霧式酸性氧化溶液，也被用來檢測對嚴重急性呼吸道症候群冠狀病毒 (SARS-CoV-2) 的殺病毒效果，以及評估對人體鼻腔與口腔粘膜的耐受性，結果發現此種製劑具有降低上呼吸道病毒載量的潛在治療作用 (Giarratana *et al*. 2021)。美國環境保護協會 (Environmental Protection Association US; EPAUS) 允許 HOCl 應用於研發智慧型預防消毒室 (smart prefabricated sanitising chamber; SPSC)，以防止 SARS-CoV-2 的傳染，試驗顯示採用噴霧方式進行 60 s，有效濃度設定在 20 mg L^{-1} 且粒徑小於 200 μm 時，可增加與病原體接觸面積並達到充分消毒的目標 (Nguyen *et al*. 2021)。

雖有學者研究指出，以培養皿盛裝 HOCl 溶液並放置在較高溫度 (≥ 25℃) 或日照環境下，易使其發生解離並失去殺菌活性 (Ishihara *et al*. 2017)，不過，該篇報導並未檢測試驗當時之光照強度；另外，未來考量應用植物組織培養技術建立無菌培植體的過程中，可能使用經高溫高壓 (121℃、1.05 kg cm^{-2}) 滅菌處理的 HOCl 溶液進行培植體清洗作業。因此，本試驗之主要目的，在於檢測以血清瓶盛裝的 HOCl 溶液，經不同光照強度或高溫高壓滅菌處理後的 HOCl 含量變化；另選取植株根部具有清熱利濕與解毒消腫等功效之保健植物-細本山葡萄 (*Vitis thunbergii* Sieb. & Zucc.) (Chiu & Chang 1995) 莖節作為材料，探討含不同濃度 HOCl 溶液進行外部消毒處理，對於建立無菌培植體與降低微生物汙染的效用，試驗所得結果，能夠提供以 HOCl 取代一般常見 NaOCl 消毒法的可行性評估，從而減少 NaOCl 的使用量並降低其對自然環境造成的不良影響。

材料與方法

供試材料與預處理

材料來源

本試驗使用的細本山葡萄 (品系編號 B-11)，係自 2017 年開始栽種於農業部農業試驗所作物組位於南溫室的種原圃，每一棵植株單獨種植於盛裝泥炭土的 15 吋花盆中，株齡約達 6 年；栽培管理模式為每隔 3 mo 酌量施用複合性化學肥料 1 次，平日採用滴灌管定時給水。本年度在 2 月份進行修剪，至 7 月份時，選取當年生健壯枝條作為供試材料。

不同濃度 HOCl 溶液之製備

本試驗所需之 HOCl 溶液係採用家庭型微酸性次氯酸水生成機 (HOCL 0.2t，衛康商貿股份有限公司，臺灣桃園市) 搭配 G-MAT 稀鹽酸電解輔助液製備而成。HOCl 溶液生成量為 0.40–0.42 L min^{-1}；另因製備完成含 HOCl 原液濃度約為 200 mg L^{-1}，故取每包含 0.12 g 粉狀 HOCl 檢測試劑 (SIBATA AQ-102，柴田科

學株式會社，日本東京都) 溶解於 10 mL HOCl 原液後，使用數位型 HOCl 檢測儀 (SIBATA AQ-202P，柴田科學株式會社，日本東京都) 測定 HOCl 實際濃度，再將原液混合純水稀釋，調配符合各處理組所需之供試濃度。

材料外部清洗與預處理

自種原圃採集到的細本山葡萄枝條，先以乾淨清水充分沖洗去除外部附著的塵土，再將藤蔓狀枝條用整枝剪裁切成長度相近的莖段，每一莖段依據節間長度之不同，約含有 5–10 個節位。在室內將這些莖段逢機分成 5 組，將基部分別插入盛裝有純水 (對照組)、50、100、150 及 200 mg L^{-1} 等不同濃度 HOCl 溶液的深褐色血清瓶中靜置 3 d。由於 HOCl 的莫耳質量為 52.46 g mol^{-1}，若將含有濃度分別為 50、100、150 及 200 mg L^{-1} 的 HOCl 溶液，換算成可供參照的體積毫莫耳濃度 (millimolar; mM) 時，則依序為 0.95、1.91、2.86 及 3.81 mM。

不同盛裝容器與光照處理對 HOCl 濃度降解的影響

試驗前，先檢測微酸性次氯酸水生成機製備的原液含 HOCl 濃度為 198.3 ± 3.4 mg L^{-1} (對照組)；另外，設計 5 個不同的處理組進行 HOCl 濃度降解試驗，分別為：(1) 以透明玻璃血清瓶盛裝原液，置入不見光的暗櫃處理 (dark cabinet, transparent glass bottled; DCT)；(2) 以透明血清瓶盛裝再置於室外陽光下照射處理 (outdoor, transparent glass bottled; OT)；(3) 以深褐色血清瓶盛裝再置於室外陽光下照射處理 (outdoor, brown glass bottled; OB)；(4) 以透明玻璃血清瓶盛裝再置於光照度 PPFD 為 4.5–10.8 µmol m^{-2} s^{-1} 的室內處理 (indoor, transparent glass bottled; IT)；以及 (5) 以深褐色玻璃血清瓶盛裝再置於光照度 PPFD 為 4.5–10.8 µmol m^{-2} s^{-1} 的室內處理 (indoor, brown glass bottled; IB)。上述每一種處理包含 3 瓶原液，且在試驗期間，每 1 d 檢測瓶內溶液之 HOCl 濃度 1 次，連續檢測 5 d，藉此瞭解各處理組溶液的 HOCl 濃度降解趨勢。為進一步量測 OT 與 OB 處理組在夏季 7 月置於室外陽光下照射處理時之光照度，故每天設定 3 個量測時間點 (上午 8 點、中午 12 點及下午 4 點)，用數位式照度計 (BENETECH GM1010，標智儀表公司，中國深圳市) 測量當時單位面積 (m^2) 的流明度 (Lux)，再依據 Lux 與太陽光譜的光合成光子流量密度 (photosynthetic photon flux density; PPFD) 換算公式：1 Lux = 0.0185 µmol m^{-2} s^{-1} PPFD 進行單位轉換。

殺菌釜高溫高壓滅菌後對 HOCl 濃度降解之影響

使用殺菌釜消毒之前，先檢測供試原液含 HOCl 的平均濃度為 198.3 ± 3.4 mg L^{-1} (before autoclaved; BA，對照組)；另以透明血清瓶盛裝，再置入殺菌釜中以 121℃、1.05 kg cm^{-2} 高溫高壓條件滅菌 15 min (after autoclaved; AA)，待供試溶液冷卻至常溫後，立即檢測其 HOCl 濃度 (AA-day 0)；此後，將溶液置於密閉不透光的殺菌釜中 4 d，在存放期間每隔 1 d 依序檢測 1 次 HOCl 濃度之變化 (AA-day 1、AA-day 2、AA-day 3 及 AA-day 4)。

細本山葡萄枝條插入不同濃度 HOCl 溶液 3 d 後對幼芽與葉片外觀之影響

如先前材料外部清洗與預處理所述之步驟，將種原圃採集到的細本山葡萄枝條，以清水沖洗後，裁切成含有 5–10 個節位的莖段。將這些莖段分成 5 組，再將基部分別插入盛裝有純水 (對照組)、50、100、150 及 200 mg L^{-1} 等不同濃度 HOCl 溶液的深褐色血清瓶中，靜置於光照度 PPFD 為 4.5–10.8 µmol m^{-2} s^{-1} 的室內 3 d；此後，觀察比較不同濃度的 HOCl 溶液對細本山葡萄幼芽與葉片生育及顏色變化之影響。

不同濃度的 HOCl 溶液消毒處理對細本山葡萄莖節培植體汙染率之影響

取枝條基部插入盛裝有純水 (對照組)、50、100、150 及 200 mg L^{-1} 等不同濃度 HOCl 溶液 3 d，初步完成第一階段預處理後之細本山葡萄插枝 (每枝含有 5–10 個莖節)，先用整枝剪去除葉片，再將枝條基部各自浸漬於與

原預處理時相同 HOCl 濃度的新製備溶液中，以柔韌拭鏡紙 (ZEISS LENS WIPES，卡爾蔡司股份有限公司，臺灣新竹縣) 擦洗著生有緻密絨毛的莖段表面進行第二階段外部消毒；此後，將各組插枝分別截切成 2–3 cm 長度的莖節培植體備用。對照組莖節培植體首先以 75% (v/v) 酒精浸漬震盪 1 min，再用 0.6% (w/v) NaOCl 溶液消毒 20 min 後，在無菌操作臺上以無菌水清洗 3 次，完成第三階段消毒程序；其餘各處理組之第三階段消毒程序，則是在使用 75% (v/v) 酒精浸漬震盪 1 min 後，於無菌操作臺上各自以含有 50、100、150 或 200 mg L^{-1} 等不同濃度的 HOCl 溶液浸漬消毒 20 min，且消毒完成後不再使用無菌水清洗。

經過第三階段消毒程序後之各處理組莖段，以解剖刀切取長約 1.5–2 cm 的培植體，接種於含 MS (Murashige & Skoog 1962) 基本鹽類、0.2 mg L^{-1} 6-benzylaminopurine (BA)、30 g L^{-1} 蔗糖及 0.8% (w/v) Difco 洋菜粉，pH 值為 5.7 的固體培養基，再置於恆溫 23℃、光照度 PPFD 為 38–40 μmol m^{-2} s^{-1} 及光週期 10 h 的培養室 7 d，調查各處理組受到真菌類或細菌類微生物汙染的比率與褐化死亡率。

試驗統計分析

以上試驗除日照強度之檢測與枝條基部插入不同濃度 HOCl 溶液 3 d 後之外表觀察外，其餘每一處理皆重複 3 次，每一重複調查 3 瓶血清瓶盛裝的 HOCl 溶液或接種 30 支試管 (每支試管接種 1 個莖節培植體)，以獲得的數據資料計算其算術平均值與標準差 (standard deviation; SD)；另以 CoStat 6.311 統計軟體進行變方分析 (analysis of variance; ANOVA)，在 5% 顯著性水準下以最小顯著差異性測驗 (least significant difference test; LSD test) 檢定各處理間差異的顯著性。

結果

不同盛裝容器與光照處理對 HOCl 濃度降解的影響

表 1 結果顯示，試驗採用的 HOCl 水生成機製造的原始溶液，經檢測含 HOCl 平均濃度為 198.3 ± 3.4 mg L^{-1} (對照組)，以透明玻璃血清瓶盛裝的 HOCl 溶液，置入不見光的暗櫃處理 (DCT)，經過 1 d 後檢測瓶中溶液含 HOCl 平均濃度為 198.7 ± 1.9 mg L^{-1}，與對照組比較後並無顯著差異；以透明玻璃血清瓶盛裝再置於陽光下照射者 (OT)，經 1 d 後瓶中溶液之 HOCl 平均濃度驟降為 8.0 ± 1.4 mg L^{-1}，顯著低於對照組與其他處理組；若以深褐色血清瓶盛裝再置於陽光下照射者 (OB)，則經過 1 d 後之溶液，其 HOCl 平均濃度降為 177.0 ± 5.4 mg L^{-1}，仍顯著低於對照組；至於，以透明玻璃血清瓶盛裝再置於光照度 PPFD 為 4.5–10.8 μmol m^{-2} s^{-1} 的室內 1 d 之處理者 (IT)，瓶中溶液的 HOCl 平均濃度為 197.7 ± 1.3 mg L^{-1}，同樣環境條件但使用深褐色血清瓶盛裝之處理組 (IB)，其測得之 HOCl 平均濃度為 199.0 ± 1.4 mg L^{-1}，二者皆與對照組無顯著差異。前述各處理組，依序處理 2、3、4 及 5 d 後，所獲得的 HOCl 濃度降解趨勢，與處理 1 d 的結果相似，但 OT 組在第 2 天後已未檢測到 HOCl 含量，儀器顯示之濃度為 0 mg L^{-1}；OB 組在陽光照射第 2、3、4 及 5 天後之濃度顯現逐日降低，分別為 155.7 ± 9.8、127.7 ± 12.3、106.0 ± 13.4 及 98.7 ± 12.4 mg L^{-1}，皆顯著低於同一天相較之對照組或 DCT (200.0 ± 0.8、195.0 ± 2.9、197.0 ± 1.4 及 197.0 ± 2.8 mg L^{-1})、IT (201.3 ± 2.4、197.7 ± 0.9、191.0 ± 2.5 及 191.7 ± 2.6 mg L^{-1}) 及 IB (201.7 ± 2.6、199.3 ± 0.9、195.7 ± 0.9 及 194.7 ± 2.9 mg L^{-1}) 等處理組。本試驗進行中，也量測收集 OT 與 OB 處理組血清瓶在夏季 7 月置於陽光下照射處理時之光照度供參考 (附錄)，第 1 天 3 個檢測時間點 (上午 8 點、中午 12 點及下午 4 點) 的光照度 PPFD 分別為 1,295、2,868 及 925 μmol m^{-2} s^{-1}；第 2 天分別為 1,321、2,462 及 1,367 μmol m^{-2} s^{-1}；第 3 天分別為 1,800、2,544 及 916 μmol m^{-2} s^{-1}；第 4 天上午 8 點與中午 12 點檢測光照度 PPFD 分別為 1,804 與 2,424 μmol m^{-2} s^{-1}，但下午 4 點遇夏季午後雷陣雨天氣，當時檢測僅有 43 μmol m^{-2} s^{-1}；至於，第 5 天中午以後仍受多雲時陰天氣影響。因此，3 個檢測時間點光照度 PPFD 分別為 1,615、356 及 581 μmol m^{-2} s^{-1}。

表 1. 盛裝次氯酸 (HOCl) 容器與光照處理對次氯酸濃度變化之影響。

Table 1. Effects of containers containing hypochlorous acid (HOCl) and lighting treatments on changes in HOCl concentration.

Treatments[z]	Days of lighting treatment and HOCl concentrations (mg L^{-1})				
	Day 1	Day 2	Day 3	Day 4	Day 5
Control	198.3 ± 3.4 a[y]	198.3 ± 3.4 a	198.3 ± 3.4 a	198.3 ± 3.4 a	198.3 ± 3.4 a
DCT	198.7 ± 1.9 a	200.0 ± 0.8 a	195.0 ± 2.9 a	197.0 ± 1.4 a	197.0 ± 2.8 a
OT	8.0 ± 1.4 c	0.0 c	0.0 c	0.0 c	0.0 c
OB	177.0 ± 5.4 b	155.7 ± 9.8 b	127.7 ± 12.3 b	106.0 ± 13.4 b	98.7 ± 12.4 b
IT	197.7 ± 1.3 a	201.3 ± 2.4 a	197.7 ± 0.9 a	191.0 ± 2.5 a	191.7 ± 2.6 a
IB	199.0 ± 1.4 a	201.7 ± 2.6 a	199.3 ± 0.9 a	195.7 ± 0.9 a	194.7 ± 2.9 a

[z] Control: The original concentration of hypochlorous acid. Indoor illumination: 4.5–10.8 μmol m^{-2} s^{-1} PPFD. Outdoor sun illumination: Refer to Appendix for daily detection values. DCT: dark cabinet, transparent glass bottled; OT: outdoor, transparent glass bottled; OB outdoor, brown glass bottled; IT: indoor, transparent glass bottled; IB: indoor, brown glass bottled.

[y] Means and standard deviation within each column followed by the same letter are not significantly different at 5% level by Fisher's protected least significance difference (LSD) test (*n* = 3).

殺菌釜高溫高壓滅菌後對 HOCl 濃度之影響

圖 1 結果顯示，將含有平均濃度為 198.3 ± 3.4 mg L^{-1} 的 HOCl 溶液 (BA；對照組) 以透明玻璃血清瓶盛裝，再置入殺菌釜中以 121℃、1.05 kg cm^{-2} 高溫高壓條件消毒 15 min，待供試溶液冷卻至常溫後，立即檢測其 HOCl 平均含量為 191.7 ± 0.9 mg L^{-1} (AA-day 0)，略低於未經高溫高壓滅菌前之對照組，二者比較後並無顯著差異；若是高溫高壓滅菌且冷卻至常溫後，再靜置於密閉不透光的殺菌釜中 1 d (AA-day 1)，檢測血清瓶內供試溶液的 HOCl 平均含量為 192.3 ± 1.7 mg L^{-1}，與對照組比較後仍無顯著差異；如繼續在殺菌釜中存放到第 2 天 (AA-day 2) 與第 3 天 (AA-day 3)，檢測供試溶液 HOCl 平均含量分別為 188.3 ± 3.9 與 184.7 ± 4.5 mg L^{-1}，二者與對照組 (198.3 ± 3.4 mg L^{-1}) 比較已有顯著降低；至於，供試溶液在殺菌釜中存放到第 5 天 (AA-day 5)，其 HOCl 平均含量與先前檢測的數據相較，也顯著降低至 177.7 ± 2.9 mg L^{-1}。

細本山葡萄枝條插入不同濃度 HOCl 溶液 3 d 後對幼芽與葉片外觀之影響

自細本山葡萄種原圃修剪採集的藤蔓狀枝條，截切成每段包含 5 個莖節的插枝，再分別將基部插入盛裝有純水 (對照組)、50、100、150 及 200 mg L^{-1} HOCl 溶液的深褐色血清瓶中 3 d，觀察結果顯示，3 d 後各處理組的插枝皆能維持一定的含水量且呈現正常生育狀態，未見枝葉萎凋或褐化死亡；即使基部浸漬於含 200 mg L^{-1} HOCl 溶液之枝條幼芽與葉片，不論在葉色或外部性狀與其他處理組相互觀察比較，也無明顯之差異。

不同濃度的 HOCl 溶液消毒處理對細本山葡萄莖節培植體汙染率之影響

經過 3 階段消毒程序之細本山葡萄各處理組莖段培植體，接種於培養基中培養 7 d 後，結果顯示，一般常用的 0.6% (w/v) NaOCl 消毒方法 (對照組)，平均有 82.2 ± 1.6% 受到微生物的汙染 (表 2)；全程使用含 50 mg L^{-1} HOCl 溶液消毒的處理組，平均仍有 74.4 ± 4.2% 高汙染率，其與對照組比較並無顯著差異；全程使用含 100 mg L^{-1} HOCl 溶液消毒的處理組，汙染率略降至 66.7 ± 5.4%，其與使用 50 mg L^{-1} HOCl 溶液消毒的處理組比較雖無顯著差異，但已顯著低於對照組 (82.2 ± 1.6%)；若使用含 150 或 200 mg L^{-1} HOCl 溶液進行全程消毒之處理組，在莖節培植體接種 7 d 後之汙染率分別降低為 61.1 ± 5.7% 與 57.8 ± 4.2 %，皆顯著低於對照組或使用 50 mg L^{-1} HOCl 溶液消毒之處理組。調查對照組與使用不同濃度的 HOCl 溶液進行消毒後，造成莖節培植體褐化死亡的比率，則結果顯示，使用含

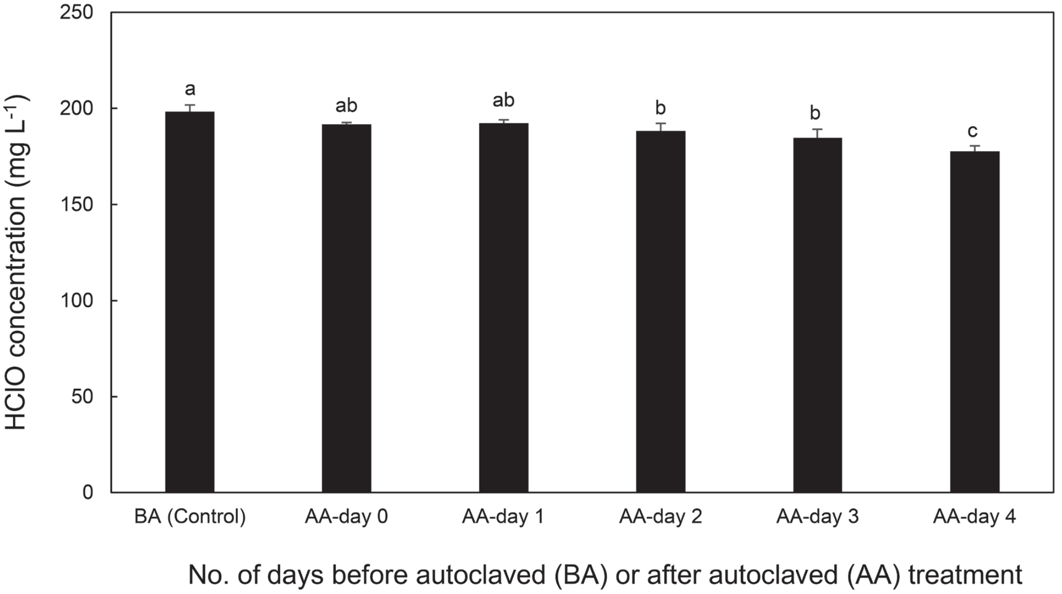

圖 1. 次氯酸 (HOCl) 溶液在殺菌釜高壓滅菌前 (BA) 或高壓滅菌後 (AA) 逐日之濃度變化。

Fig. 1. Daily concentration changes of hypochlorous acid (HOCl) solution before autoclaved (BA) or after autoclaved (AA). Vertical bars indicate standard deviation (*n* = 3). Mean values with the same letter are not significantly different at 5% level by Fisher's protected least significance difference (LSD) test (*n* = 3).

表 2. 含不同濃度的次氯酸 (HOCl) 溶液滅菌處理對細本山葡萄莖節培植體汙染率之影響。

Table 2. Effects of different concentrations of hypochlorous acid (HOCl) solution disinfection treatments on the contamination rates of *Vitis thunbergii* Sieb. & Zucc. stem node explants.

HOCl concentration (mg L^{-1})	Stem explants after cultured for 7 d	
	Contamination rate (%)	Browning rate (%)
0 (control)[z]	82.2 ± 1.6 a[y]	2.2 ± 1.6 a
50	74.4 ± 4.2 ab	1.1 ± 1.6 a
100	66.7 ± 5.4 bc	0.0 a
150	61.1 ± 5.7 c	1.1 ± 1.6 a
200	57.8 ± 4.2 c	2.2 ± 1.6 a

[z] The stem node explants were surface-disinfected in 75% (v/v) ethanol solution for 60 s, followed by 0.6% (w/v) sodium hypochlorite solution with 2 drops of Tween 20® per 100 mL under ultrasonic vibration for 20 min and rinsed 3 times with sterile distilled water.

[y] Means and standard deviation within each column followed by the same letter are not significantly different at 5% level by Fisher's protected least significance difference (LSD) test (*n* = 3).

50、100、150 及 200 mg L^{-1} 等不同濃度 HOCl 溶液之處理組，莖節培植體平均褐化死亡率均介於 0–2.2%，與使用 0.6% (w/v) NaOCl 消毒的對照組 (2.2%) 比較後，彼此間均無顯著差異。

討論

HOCl的合成或製備有許多種方法，例如，可由 NaDCC 水溶液在水解過程中產生，也能在人類或其他哺乳類動物的血液嗜中性白血球中，自行藉由含血紅素酵素 (heme enzyme) 的髓過氧化物酶 (myeloperoxidase; MPO) 作用，將體內氯化物 (Cl^-) 與過氧化氫 (H_2O_2) 進行轉化與合成，再進一步與牛磺酸反應生成低毒性的牛磺酸氯胺 (TauCl) 抗發炎物質，用來抵禦與消滅入侵體內的病原菌 (Pekoe *et al.* 1982;

Wang *et al*. 2007; Maitra *et al*. 2013)；此外，透過電解 0.85% (w/v) 食鹽 (NaCl) 稀釋液 (Kim *et al*. 2008; Kubota *et al*. 2009)，或是利用非隔膜電解池電解 6% (v/v) 鹽酸 (HCl) 稀釋液，也能生產出濃度約為 40 mg L^{-1} HOCl 的微酸性電解水 (Jafry *et al*. 2017)。本試驗製備的 HOCl 溶液應用前述類似技術，藉由次氯酸水生成機電解稀釋鹽酸溶液而成，此一設備在控制出水量為 0.4–0.42 L min^{-1} 條件下，可產製出含 HOCl 濃度約為 200 mg L^{-1} 的原液。

HOCl 雖是一種可供培植體外部消毒之強氧化劑，卻可能因溶液酸鹼值 (pH) 升高、盛裝容器氣密性不足或長期曝露於日光或紫外光照射環境下，使溶液內多數的 HOCl 降解變成氫離子 (H^+) 與次氯酸根離子 (OCl^-)，或產生氧化還原反應生成氯氣進而散失在空氣中，使得 HOCl 濃度降低影響殺菌功效 (Wang *et al*. 2007; Morgenthau *et al*. 2012)；本試驗係採用透明或深褐色玻璃血清瓶盛裝 HOCl 溶液並加蓋密封，因此較無氯氣散失等問題。經檢測得知，以透明血清瓶盛裝的處理組 (OT) 曝晒於夏季自然光照下 8 h 後，溶液中 HOCl 平均濃度即自 198.3 ± 3.4 mg L^{-1} 驟降為 8.0 ± 1.4 mg L^{-1}，顯著低於原液濃度 (對照組) 與放置於室內或暗櫃中的處理組 (表 1)；若使用深褐色血清瓶盛裝者，則能阻擋大部分的光線照射量，故 HOCl 平均濃度仍有 177.0 ± 5.4 mg L^{-1}，此結果與 Ishihara *et al*. (2017) 的報導相似，顯示高光照強度與紫外線易使 HOCl 產生降解作用；至於，HOCl 溶液經滅菌釜以 121℃、1.05 kg cm^{-2} 高溫高壓條件消毒 15 min 後，其 HOCl 平均濃度仍有 191.7 ± 0.9 mg L^{-1} (AA-day 0)，雖略低於對照組的 198.3 ± 3.4 mg L^{-1}，但二者比較並無顯著差異 (圖 1)，只是隨著靜置天數的增加，瓶內 HOCl 的濃度才逐漸解離，顯示高溫高壓處理雖對 HOCl 降解略有影響，但不及高光照強度的影響大。

為測試含 HOCl 溶液對細本山葡萄枝條正常生育是否產生影響，並作為後續培植體外部消毒與組織培養試驗時之參考，故將採集自露天種原圃的藤蔓狀枝條，截切成每段包含 5 個莖節的插枝，再分別插入盛裝有純水 (對照組)、50、100、150 或 200 mg L^{-1} HOCl 溶液的深褐色血清瓶中 3 d，觀察結果得知，即使基部浸漬於最高濃度含 200 mg L^{-1} HOCl 溶液之枝條葉片與幼嫩新芽並無萎凋或褐化死亡，不論葉色或外部性狀與其他處理組比較也無明顯差異，此與 Parkinson *et al*. (1996) 所述論點相似，即使用 300 mg L^{-1} 的 NaDCC 進行嫩枝消毒 24–48 h，與使用 $HgCl_2$ 及 $Ca(ClO)_2$ 消毒效果相當，且對植物體的毒性不高。已知 NaDCC 莫耳質量為 220 g M^{-1}，溶解於水中會水解產生 2 莫耳質量的 HOCl，因 HOCl 每莫耳質量為 52.46 g M^{-1}，據此換算濃度 300 mg L^{-1} NaDCC 的溶液中，約含有 143 mg L^{-1} HOCl。

應用植物組織培養技術建立無菌培植體時，首先面臨的難題，即是如何進行培植體的外部消毒與有效防止真菌或細菌微生物的汙染，一般取得較便利且較常被使用的消毒劑為酒精與 NaOCl (Pereira *et al*. 2011)；De Mello *et al*. (2020) 曾報導指出，在猴缽樹 (*Lecythis pisonis* Cambess) 莖節消毒試驗中，單獨使用 3% 或 5% (w/v) NaOCl 溶液消毒培植體之汙染率均高達 93.25%；若使用 3% (w/v) NaOCl 溶液搭配 500 或 1,000 mg L^{-1} 阿莫西林 (amoxicillin) 抗生素消毒 20 min，則分別能降低培植體汙染率至 46.75% 與 33.25%，但培養基中若添加阿莫西林抗生素 21 d 後，會對培植體產生毒化作用導致芽體生長異常。在一項香波樹 (*Stelechocarpus burahol*) 種胚消毒研究中，學者們先自果實中取出種子，再依序採用 2 g L^{-1} 洗滌劑浸漬 10 min、2 g L^{-1} 殺菌劑浸漬 60 min 及 2 g L^{-1} 殺真菌劑浸漬 60 min 等方法進行預滅菌處理，這些種子經無菌水清洗 3 次後，以 70% (v/v) 酒精消毒 3 s，最終切取種胚作為供試材料。此後，種胚分別以不同濃度 NaOCl (5%、10%，w/v)，浸漬消毒 5 min 或 10 min，經接種於培養基 60 d 後，結果以 5% (w/v) NaOCl 溶液消毒 5 min 之處理方法最佳，培植體未發現有汙染情形，且存活率為 88.89%，不過，種胚褐化死亡率達 11.11% (Handayani *et al*. 2022)，顯示培植體預滅菌處理有助於降低微生物汙染率，但後續使用消毒液所含 NaOCl 濃度仍不宜過高，以免傷害幼嫩的培植體。

本研究將細本山葡萄插枝基部分別插入盛裝有不同濃度 HOCl 溶液的血清瓶 3 d，以期藉由導管組織的輸導作用，讓 HOCl 先去除植物體中的病毒與內生菌；此後，在各處理組插枝剪去葉片後，重新浸漬於與原處理組有相同 HOCl 濃度的新製備溶液，以拭鏡紙擦洗著生細密絨毛的莖段進行預消毒，此種供試材料經 75% (v/v) 酒精浸漬 1 min，再用含 0.6% (w/v) NaOCl 溶液消毒 20 min (對照組)，發現培植體接種 7 d 後受微生物汙染比率仍高達 82.2 ± 1.6% (表 2)，這些污染微生物菌種經進一步分離與鑑別，則多數屬於真菌類如 *Lasiodiplodia theobromae*，少數為革蘭氏陰性桿菌如 *Methylobacterium radiotolerans* 等 (作者未發表資料)；本試驗雖受限於家庭型次氯酸水生成機僅能製造出最高濃度約含 200 mg L^{-1} HOCl 溶液，但取此原液進行培植體外部消毒，進而省略再以無菌水清洗的繁瑣程序，最終仍可顯著降低微生物汙染率至 57.8 ± 4.2%，且未受汙染的莖節經培養 21 d 後依然正常發芽生長，未見 HOCl 有毒害培植體的現象產生 (圖 2)。根據學者們報導指出，微酸性 HOCl 對動、植物的毒性較低。因此，兼具環保與安全的 NaDCC 水解產生之 HOCl 可作為培植體主要的殺菌劑，或將其添加在植物組織培養用的培養基中替代其他抗菌物質 (Shetty & Narasimhan 2021)；另有研究發現，HOCl 對大腸桿菌 (*Escherichia coli*)、金黃色葡萄球菌 (*Staphylococcus aureus*) 及仙人掌芽孢桿菌 (*Bacillus cereus*) 等細菌類或酵母菌微生物皆有抑菌作用 (Niedz & Bausher 2002; Bonvillain *et al*. 2011; Forghani *et al*. 2015; Quan *et al*. 2017)，此也與本試驗檢視受微生物汙染的莖節培植體樣本中，屬於細菌類汙染者比例較少，而大多數為真菌類汙染的結果相符合 (作者未發表資料)。因此，開發應用物理方法或化學殺菌劑以有效抑制真菌類滋生並降低培植體汙染率的技術，仍值得繼續探討與研究。

結論

綜合以上各項試驗結果所得結論，HOCl

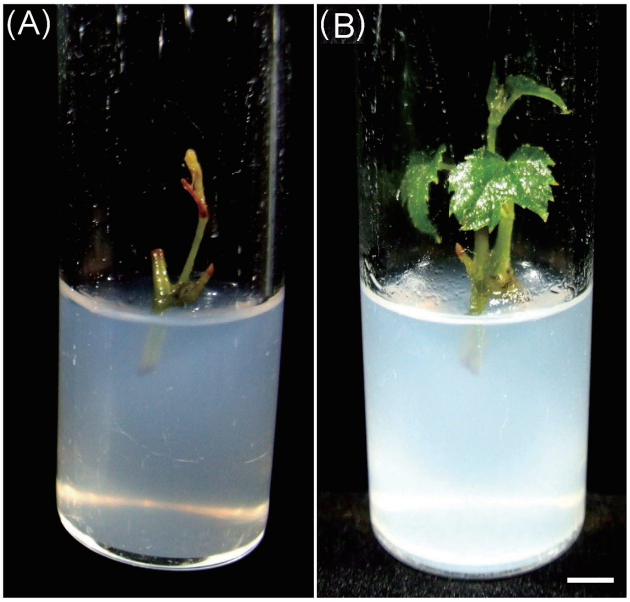

圖 2.　(A) 細本山葡萄莖節以 200 mg L^{-1} 次氯酸 (HOCl) 滅菌後，再接種於培養基 7 d 的培植體外觀；(B) 一些莖節培植體在培養 21 d 後，已有新葉與幼芽發育生長。

Fig. 2.　(A) The growth appearance of *Vitis thunbergii* Sieb. & Zucc. stem node segment after being disinfected with 200 mg L^{-1} hypochlorous acid (HOCl) and inoculated into the culture medium for 7 d; and (B) after 21 d of cultivation, new leaves and buds have developed from some stem node explant. (Scale bar = 0.5 cm)

溶液盛裝於深褐色血清瓶，並放置在室內、常溫且避免陽光直射的環境，可維持其穩定性達 5 d 以上；應用組織培養技術建立細本山葡萄無菌培植體時，使用 150–200 mg L^{-1} HOCl 溶液進行外部消毒的莖節培植體汙染率，顯著低於使用一般 NaOCl 消毒之對照組，在消毒過程中不但省去無菌水清洗程序，且經長期觀察也未影響培植體正常發育。因此，應用 HOCl 取代 NaOCl 進行滅菌與消毒的可行性甚高，對於呼應永續維護潔淨的自然環境，並逐步減少 NaOCl 使用量的倡議將有正面助益。

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引用文獻

Bonvillain, R. W., R. G. Painter, E. M. Ledet, and G. Wang. 2011. Comparisons of resistance of CF and non-CF pathogens to hydrogen peroxide and hypochlorous acid oxidants *in vitro*. BMC Microbiol. 11:112. doi:10.1186/1471-2180-11-112

Boonrattanakij, N., S. Yomchinda, F. J. Lin, L. M. Bellotindos, and M. C. Lu. 2021. Investigation and disinfection of bacteria and fungi in sports fitness center. Environ. Sci. Pollut. Res. 28:52576–52586. doi:10.1007/s11356-021-14323-5

Chiu, N. Y. and K. H. Chang. 1995. Hsiao-pen shan-p’u-t’ao. p.147–148. *in*: The Illustrated Medicinal Plants of Taiwan. Vol. 4. SMC Publishing Inc. Taipei, Taiwan. 319 pp. (in Chinese)

De Mello, T., E. de Oliveira Gonçalves, R. S. Alexandre, E. R. Schmildt, and W. C. Otoni. 2020. Establishment and *in vitro* morphogenesis of sapucaia explants (Lecythidaceae). In Vitro Cell. Dev. Biol. Plant 56:882–893. doi:10.1007/s11627-020-10091-y

De Santana, J. R. F., R. Paiva, A. V. de Souza, and L. M. de Oliveira. 2011. Effect of different carbon sources on the *in vitro* multiplication of *Annona* sp. Ciênc. Agrotec. 35:487–493. doi:10.1590/S1413-70542011005000002

Emmanuel, E., G. Keck, J. M. Blanchard, P. Vermande, and Y. Perrodin. 2004. Toxicological effects of disinfections using sodium hypochlorite on aquatic organisms and its contribution to AOX formation in hospital wastewater. Environ. Int. 30:891–900. doi:10.1016/j.envint.2004.02.004

Forghani, F., M. Eskandari, and D. H. Oh. 2015. Application of slightly acidic electrolyzed water and ultrasound for microbial decontamination of kashk. Food Sci. Biotechnol. 24:1011–1016. doi:10.1007/s10068-015-0129-5

Giarratana, N., B. Rajan, K. Kamala, M. Mendenhall, and G. Reiner. 2021. A sprayable Acid-Oxidizing solution containing hypochlorous acid (AOS2020) efficiently and safely inactivates SARS-Cov-2: A new potential solution for upper respiratory tract hygiene. Eur. Arch. Oto-Rhino-L. 278:3099–3103. doi:10.1007/s00405-021-06644-5

Gomes, G. A. C., R. Paiva, R. C. Herrera, and P. D. de Oliveira Paiva. 2010. Micropropagation of *Maclura tinctoria* L.: An endangered woody species. Rev. Árvore. 34:25–30. doi:10.1590/S0100-67622010000100003

Handayani, E., M. B. Irsyadi, R. L. M. N. Alawiyah, and I. Aris. 2022. Effect of explants sterilization and plant growth regulators on embryo culture of kepel (*Stelechocarpus burahol*). 4th ICoSA 2021 IOP Conf. Ser.: Earth Environ. Sci. 985:012016. doi:10.1088/1755-1315/985/1/012016

Hao, J., T. Wu, H. Li, and H. Liu. 2017. Differences of bactericidal efficacy on *Escherichia coli*, *Staphylococcus aureus*, and *Bacillus subtilis* of slightly and strongly acidic electrolyzed water. Food Bioproc. Tech. 10:155–164. doi:10.1007/s11947-016-1801-3

Hashim, S. N., S. Z. Ghazali, N. J. Sidik, C. C. Tay, and A. Saleh. 2021. Surface sterilization method for reducing contamination of *Clinacanthus nutans* nodal explants intended for *in-vitro* culture. E3S Web Conf. 306:01004. doi:10.1051/e3sconf/202130601004

Ishihara, M., K. Murakami, K. Fukuda, S. Nakamura, M. Kuwabara, H. Hattori, ... H. Yokoe. 2017. Stability of weakly acidic hypochlorous acid solution with microbicidal activity. Biocontrol Sci. 22:223–227. doi:10.4265/bio.22.223

Jafry, A. T., C. Lee, D. Kim, G. Han, W. K. Sung, and J. Lee. 2017. Development of high concentrated slightly acidic hypochlorous acid generator for food safety. J. Mech. Sci. Technol. 31:4541–4547. doi:10.1007/s12206-017-0854-1

Kim, H. J., J. G. Lee, J. W. Kang, H. J. Cho, H. S. Kim, H. K. Byeon, and J. H. Yoon. 2008. Effects of a low concentration hypochlorous acid nasal irrigation solution on bacteria, fungi, and virus. Laryngoscope 118:1862–1867. doi:10.1097/MLG.0b013e31817f4d34

Kubota, A., K. Nose, T. Yonekura, T. Kosumi, K. Yam-

auchi, and H. Oyanagi. 2009. Effect of electrolyzed strong acid water on peritoneal irrigation of experimental perforated peritonitis. Surg. Today 39:514–517. doi:10.1007/s00595-008-3914-4

Ma, S. X. and C. T. Shii. 1992. Overview of the development of plant tissue culture. p.11–14. *in*: Tissue Culture Technology in Horticultural Crops. Harvest farm magazine. Taipei, Taiwan. 120 pp. (in Chinese)

Maitra, D., F. Shaeib, I. Abdulhamid, R. M. Abdulridha, G. M. Saed, M. P. Diamond, ... H. M. Abu-Soud. 2013. Myeloperoxidase acts as a source of free iron during steady-state catalysis by a feedback inhibitory pathway. Free Radic. Biol. Med. 63:90–98. doi:10.1016/j.freeradbiomed.2013.04.009

Mihaljević, I., K. Dugalić, V. Tomaš, M. Viljevac, A. Pranjić, Z. Čmelik, ... Z. Jurković. 2013. *In vitro* sterilization procedures for micropropagation of 'Oblačinska' sour cherry. J. Agric. Sci. 58:117–126. doi:10.2298/JAS1302117M

Morgenthau, A., A. M. Nicolae, A. E. Laursen, D. A. Foucher, G. M. Wolfaardt, and M. Hausner. 2012. Assessment of the working range and effect of sodium dichloroisocyanurate on *Pseudomonas aeruginosa* biofilms and planktonic cells. Biofouling 28:111–120. doi:10.1080/08927014.2011.654335

Murashige, T. and F. Skoog. 1962. A revised medium for rapid growth and bio assays with tobacco tissue cultures. Physiol. Plant 15:473–497. doi:10.1111/j.1399-3054.1962.tb08052.x

Nguyen, K., D. Bui, M. Hashemi, D. M. Hocking, P. Mendis, R. A. Strugnell, and S. C. Dharmage. 2021. The potential use of hypochlorous acid and a smart prefabricated sanitising chamber to reduce occupation-related COVID-19 exposure. Risk Manag. Healthc. Policy 14:247–252. doi:10.2147/RMHP.S284897

Niedz, R. P. and M. G. Bausher. 2002. Control of *in vitro* contamination of explants from greenhouse- and field-grown trees. In Vitro Cell. Dev. Biol. Plant 38:468–471. doi:10.1079/IVP2002316

Parkinson, M., M. Prendergast, and A. J. Sayegh. 1996. Sterilisation of explants and cultures with sodium dichloroisocyanurate. Plant Growth Regul. 20:61–66. doi:10.1007/BF00024060

Pekoe, G., K. V. Dyke, H. Mengoli, D. Peden, and D. English. 1982. Comparison of the effects of antioxidant non-steroidal anti-inflammatory drugs against myeloperoxidase and hypochlorous acid luminol-enhanced chemiluminescence. Agents Actions 12:232–238. doi:10.1007/BF01965152

Pereira, G. A., L. de Souza Corrêa, and A. C. Boliani. 2011. Desinfestação e estabelecimento *in vitro* de explantes de bananeira 'Grande naine' em diferentes concentrações de hipoclorito de sódio. Rev. Bras. Frutic. 33:222–226. doi:10.1590/S0100-29452011000500026

Quan, Y., H. Y. Kim, and I. S. Shin. 2017. Bactericidal activity of strong acidic hypochlorous water against *Escherichia coli* O157:H7 and *Listeria monocytogenes* in biofilms attached to stainless steel. Food Sci. Biotechnol. 26:841–846. doi:10.1007/s10068-017-0086-2

Rihan, H. Z., M. Al-Issawi, F. Al-swedi, and M. P. Fuller. 2012. The effect of using PPM (plant preservative mixture) on the development of cauliflower microshoots and the quality of artificial seed produced. Sci. Hortic. 141:47–52. doi:10.1016/j.scienta.2012.03.018

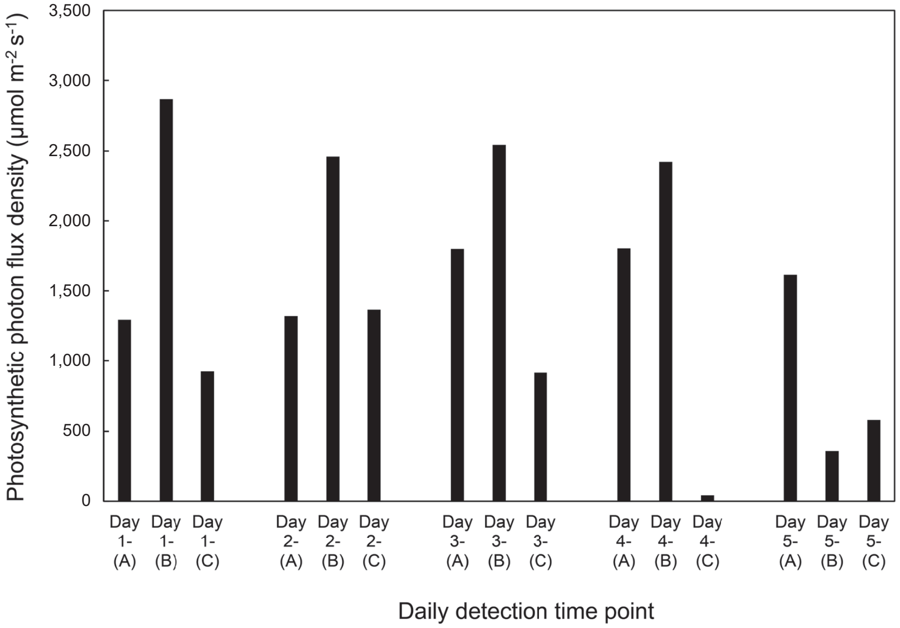
Rubinsky, L., B. Patrick, P. Mikus, and B. Rubinsky. 2016. Germicide wound pad with active, *in situ*, electrolytically produced hypochlorous acid. Biomed. Microdevices 18:26. doi:10.1007/s10544-016-0052-4

Shetty, S. C. and S. Narasimhan. 2021. Sodium dichloroisocyanurate: An eco-friendly chemical alternative for media autoclaving and explant sterilisation in plant tissue culture. Intl. J. Res. Pharm. Sci. 12:107–112.

Silva, L. C., R. Paiva, D. P. Vargas, D. P. Corrêa da Silva, S. Barbosa, and R. C. Herrera. 2015. Decontaminant solution on *in vitro* growth of *Byrsonima intermedia* seedlings. Cienc. Rural. 45:674–679. doi:10.1590/0103-8478cr20120078

Small, D. A., W. Chang, F. Toghrol, and W. E. Bentley. 2007. Toxicogenomic analysis of sodium hypochlorite antimicrobial mechanisms in *Pseudomonas aeruginosa*. Appl. Microbiol. Biotechnol. 74:176–185. doi:10.1007/s00253-006-0644-7

Wang, L., M. Bassiri, R. Najafi, K. Najafi, J. Yang, B. Khosrovi, ... M. C. Robson. 2007. Hypochlorous acid as a potential wound care agent. Part I. Stabilized hypochlorous acid: A component of the inorganic armamentarium of innate immunity. J. Burns Wounds 6:e5.



附錄 . 次氯酸 (HOCl) 溶液在室外全日照處理時之每日檢測時間點光合成光子流量密度 (PPFD)。(A) 上午 8 點；(B) 中午 12 點；(C) 下午 4 點。

Appendix. The photosynthetic photon flux density (PPFD) of daily detection time points when the hypochlorous acid (HOCl) solutions were exposed to full sunlight outdoors. (A) 8 am; (B) 12 pm; and (C) 4 pm.

Degradation Test of Hypochlorous Acid and Its Application in the Disinfection of *Vitis thunbergii* Sieb. & Zucc. Stem Node Explants

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Abstract

Shiau, Y. J., M. T. Lu, and T. C. Lin. 2024. Degradation test of hypochlorous acid and its application in the disinfection of *Vitis thunbergii* Sieb. & Zucc. stem node explants. J. Taiwan Agric. Res. 73(1):25–36.

Hypochlorous acid (HOCl) possesses potent oxidative capabilities and can disrupt the permeability of microbial cell membranes, thereby achieving sterilization. The main purpose of this study was to determine the impact of different light illuminations or high-temperature autoclaved sterilization on the degradation of HOCl. Furthermore, the study explored the effects of external disinfection treatments with different concentrations of HOCl on reducing the contamination rate of *Vitis thunbergii* Sieb. & Zucc stem node explants. The results showed that the stability of the solution containing 198.3 ± 3.4 mg L^{-1} of HOCl could be maintained for more than 5 d if it was placed in brown glass bottled indoors at room temperature in the shade. Minimal alteration in the HOCl content was observed after autoclaving. When 0.6% (w/v) sodium hypochlorite (NaOCl) solution was used for external disinfection of *Vitis thunbergii* Sieb. & Zucc stem nodes for 20 min, the explant contamination rate was 82.2 ± 1.6% (Control), which was significantly higher than the treatments using 150 and 200 mg L^{-1} HOCl solutions (61.1 ± 5.7% & 57.8 ± 4.2%). After a 21-day culture period, HOCl demonstrated no adverse effects on the normal growth of stem nodes. Thus, replacing NaOCl with HOCl for external disinfection of explants appears to be a viable alternative.

Key words: Autoclaving, Light illumination, Microbial contamination, Tissue culture.

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研究報告

溫度與日射量對紫色葉菜甘藷生長性狀及植體元素之影響

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摘要

何佳勳、楊滿霞、林慧玲。2024。溫度與日射量對紫色葉菜甘藷生長性狀及植體元素之影響。台灣農業研究 73(1):37–52。

本研究以農業部農業試驗所嘉義農業試驗分所育成紫葉品系的葉菜甘藷 CYY84-67 作為試驗材料，並於 2016–2018 年在農業部農業試驗所農場進行試驗調查，藉由每季定植 1 次連續採收 3 次，2 年期間共計蒐集 24 個不同採收期的調查數據與氣象資料。研究目的係釐清溫度與日射量對紫色葉菜甘藷生長性狀與植體元素之影響，以期瞭解紫色葉菜甘藷之最適栽培時期，闡明溫度與日射量對植體元素之消長變化。本研究利用典型相關分析，探討 2 組變數間相互關係最大的線性組合，並計算 2 組變數在線性關係最大化之權重，結果顯示紫色葉菜甘藷 CYY84-67 於春秋兩季的單位面積產量最高，利用典型相關分析顯示生育度日數、累加日射量及累加日夜溫差，是影響紫色葉菜甘藷其葉面積、葉乾重及莖乾重的氣象參數，其中又以累加日射量影響權重最大。此外，生育度日數、累加日射量及累加日夜溫差，也會影響紫色葉菜甘藷 CYY84-67 其葉片與莖部植體元素含量的變化，其中生育度日數對葉片的鈣影響權重較大，而累加日射量對莖部的磷影響權重較高。

關鍵詞：紫色葉菜甘藷、溫度、日射量、生長性狀、植體元素。

前言

葉菜甘藷 (*Ipomoea batatas* L.)，英名為 leafy sweet potato，別名為地瓜葉與過溝菜，屬於旋花科甘藷屬之一年或多年生蔓生植物。甘藷原產於熱帶美洲 (Cooley 1951)，為熱帶與亞熱帶地區重要的飼料、糧食作物及工業原料，具匍匐地面生長特性且全年四季皆可生產。再加上栽培管理容易不須多施農藥且可連續採收，因此生產成本較低，故葉菜甘藷成為國產大宗蔬菜之一。葉菜甘藷的形態含有多種葉色與葉片形狀，葉色有黃、淺綠、深綠及紫紅色，而葉片則有卵形、心形及羽狀深裂等形狀。另葉菜甘藷含有多種營養成分，其維生素 A 與 C 含量高，且含豐富蛋白質、葉酸、礦物元素 (鉀、鈣及鎂) 及膳食纖維 (Lai *et al*. 2000; Tang *et al*. 2021)。往昔文獻顯示葉菜甘藷可抑制糖尿病、白血病、病毒、結腸癌細胞及胃癌細胞的增生等 (Yoshimoto *et al*. 2002; Kurata *et al*. 2007; Ludvik *et al*. 2008)。紫色葉菜甘藷 (purple leafy sweet potato) 主要營養成分與葉菜甘藷相似，其富含酚類化合物、類黃酮及花青素等機能性成分，被視為現代物美價廉的健康蔬菜 (Chu *et al*. 2000; Rumbaoa *et al*. 2009; Gunathilake & Ranaweera 2016; Li *et al*. 2019)。

葉菜甘藷適合熱帶與亞熱帶地區栽培，在溫暖濕潤條件下生長快速，全臺栽培面積約 100 ha，栽培地區則以雲林縣西螺鎮為主，可週年採收又以 4–9 月為盛產期。此外，葉菜甘藷喜全日照、高溫環境、耐旱及耐熱，但不耐寒與長時間淹水，其生長適溫範圍為 20–30℃，在 10℃以下易發生寒害，10–15℃其生長呈休眠狀態，15℃以上可發根與發芽，

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35℃以上則有高溫障礙與生長衰退情形 (Lai & Huang 2012)。葉菜甘藷定植後至第一次採收需 40–50 d，在夏季 7–14 d 採收 1 次，冬季低溫生長緩慢約 20–25 d 才採收 1 次 (Lai & Huang 2012)。

已知溫度、日射量及養分為影響作物生長與產量的主要因子，如溫度會影響作物光合作用、礦物元素吸收及植體形態，高溫或低溫則會抑制作物生長表現 (Wurr & Fellows 1991; Yan & Hunt 1999; Kong *et al*. 2023)。太陽輻射量乃是提供作物進行光合作用的能量來源，而作物的乾物質是經由光合作用所形成，藉由作物累積截獲的光合有效輻射與利用效率所決定 (Andersen *et al*. 1996; Fochesatto *et al*. 2016)。除此，植物對養分吸收的方式可透過質流、根截取及滲透作用，且植物蒸散作用亦會影響養分吸收效率，而溫度、光照、濕度及風速等環境因子則會影響蒸散作用速率，進而改變植物對養分的吸收 (Chen 2009)。文獻研究顯示，葉菜類蔬菜的礦物質含量會隨生長階段、收穫時間、環境及栽培條件不同而有所差異 (Khader & Rama 1998; Wang *et al*. 2008; Waterland *et al*. 2017)，而葉片氮濃度則會影響葉面積光合作用與相對生長速率 (Reich *et al*. 1998)。此外，鈣離子是植物生長與發育的重要元素，可維持細胞壁結構完整性、調節氣孔、花粉管生長及根毛延伸等生理反應，而低溫則會誘導鈣離子訊息傳遞，以調節植物耐冷性基因的表現 (Sanders *et al*. 2002; White & Broadley 2003; Dodd *et al*. 2010; Iqbal *et al*. 2022)。

本研究目的旨在釐清溫度與日射量對紫色葉菜甘藷生長性狀與植體元素之影響，期瞭解紫色葉菜甘藷之最適栽培時期，並闡明溫度與日射量對植體元素之消長變化，以作為蔬菜生產之理論與應用基礎。

材料與方法

植物材料與栽培管理

本試驗以農業部農業試驗所嘉義農業試驗分所育成的心形紫葉品系 CYY84-67 作為試驗材料，並於 2016–2018 年種植在農業部農業試驗所之農場 (臺中市霧峰區)。本試驗採逢機完全區集設計 (randomized complete block design; RCBD)，田區規劃 4 重複，每畦長 5 m、寬 8 m，行距 1.2 m，共 4 畦，每重複種植 40 株扦插苗，株距固定為 0.5 m，採雙行植。田區施肥以有機質肥料新樂園 1 號 (固態粉粒狀，pH 7.7；成分為 4% N、3% P_2O_5、3% K_2O、2.1% MgO 及有機質 70%，興農股份有限公司，臺灣臺中市) 10 Mg ha^{-1}、尿素 (CH_4N_2O) 50 kg ha^{-1}、過磷酸鈣 ($Ca(H_2PO_4)_2$) 260 kg ha^{-1} 及氯化鉀 (KCl) 150 kg ha^{-1} 混合作為基肥，本試驗每定植 1 次將連續採收 3 次，每次採收後再施用尿素 (CH_4N_2O) 50 kg ha^{-1}。本研究有關葉用甘藷病蟲害防治之推薦藥劑，係參考農業部動植物防疫檢疫署農藥資訊服務網 (https://pesticide.aphia.gov.tw/information/) 所列的葉用甘藷之病蟲害防治用藥。

性狀調查與氣象資料收集

將紫色葉菜甘藷剪取約 15–20 cm 長度作為扦插苗，分別於 2016 年 3 月 7 日、6 月 7 日、8 月 30 日及 12 月 8 日定植，2017 年則在 3 月 7 日、6 月 28 日、9 月 5 日及 12 月 7 日定植，且每定植 1 次將連續採收 3 次，採收標準係以紫色葉菜甘藷覆蓋整個畦面為準 (圖 1)。另一方面，依栽植期間月份劃分栽植季節，以 3–5 月為春季 (spring)、6–8 月為夏季

圖 1. 參試材料於試驗田區達採收標準之示意照。

Fig. 1. Photo of the test plants reaching harvesting standard in the experimental field.

(summer)、9–11 月為秋季 (autumn)，而 12 月至翌年 2 月為冬季 (winter)，因此 2016–2018 年期間合計 24 個不同採收期的試驗資料 (表 1)。本試驗取樣方式為離畦面 15–20 cm 處修平，調查部位以頂端 15 cm 長之嫩梢為主，生長性狀調查項目包含單株頂芽數 (number of terminal buds)、單枝葉片數 (number of leaves per shoot)、單枝葉面積 (leaf area per shoot, cm^2)、徑寬 (diameter of stem, mm)、單枝葉乾重 (dry weight of leaves per shoot, g)、單枝莖乾重 (dry weight of stems per shoot, g)、頂芽乾重 (dry weight of terminal buds, g) 及單位面積產量 (yield per unit area, kg m^{-2})。

紫色葉菜甘藷於 2016–2018 年栽植期間分別收集臨近試區一級農業氣象測站之氣象資料，包含 (1) 累加日均溫 (accumulated daily air temperature; ADAT,℃)，累加栽植期間每日的日均溫；(2) 累加日間最高氣溫 (accumulated maximum daytime air temperature; AMDTAT, ℃)，累加栽植期間日出至日落時間的每小時最高溫度，春季累加時間為 06:00–18:00，夏季累加時間為 05:00–19:00，秋季累加時間為 06:00–18:00，冬季累加時間為 06:00–17:00；(3) 累加夜間最低氣溫 (accumulated minimum nighttime air temperature; AMNTAT,℃)，累加栽植期間日落至日出時間的每小時最低溫度，

表 1. 紫色葉菜甘藷 CYY84-67 於 2016–2018 年期間合計 24 個採收期之定植日期、收穫日期、栽培季節及收穫天數。

Table 1. Dates of planting, harvest, crop season and days to harvest time of 24 cultivation periods of purple leafy sweet potato CYY84-67 in 2016–2018.

Date of planting	Date of harvest	Crop season	Days to harvest time
2016/3/7	2016/4/20	spring	44
	2016/5/17	spring	27
	2016/6/29	summer	43
2016/6/7	2016/7/12	summer	35
	2016/8/4	summer	23
	2016/8/24	summer	20
2016/8/30	2016/10/4	autumn	34
	2016/11/3	autumn	30
	2016/11/29	autumn	26
2016/12/8	2017/1/24	winter	47
	2017/3/1	winter	36
	2017/4/5	spring	35
2017/3/7	2017/4/20	spring	44
	2017/5/17	spring	27
	2017/6/20	summer	34
2017/6/28	2017/8/11	summer	44
	2017/9/7	summer	27
	2017/9/29	autumn	22
2017/9/5	2017/10/12	autumn	37
	2017/11/9	autumn	28
	2017/12/7	autumn	28
2017/12/7	2018/2/26	winter	81
	2018/3/30	spring	32
	2018/4/26	spring	27

春季累加時間為 19:00–05:00，夏季累加時間為 20:00–04:00，秋季累加時間為 19:00–05:00，冬季累加時間為 18:00–05:00；(4) 累加日夜溫差 (accumulated diurnal temperature regimes; ADTR, ℃)，累加栽植期間每日的日間氣溫減去夜間氣溫之溫差；(5) 累加日射量 (accumulated daily solar radiation; ADSR, MJ m^{-2})，累加栽植期間每日的日輻射量；(6) 平均日均溫 (mean values of daily air temperature; MDAT, ℃)，平均栽植期間每日的日均溫；(7) 平均日間最高氣溫 (mean values of maximum daytime air temperature; MMDTAT, ℃)，平均栽植期間日出至日落時間的每小時最高溫度；(8) 平均夜間最低氣溫 (mean values of minimum nighttime air temperature; MMNTAT, ℃)，平均栽植期間日落至日出時間的每小時最低溫度；(9) 平均日夜溫差 (mean values of diurnal temperature regimes; MDTR, ℃)，平均栽植期間每日的日間氣溫減去夜間氣溫之溫差；(10) 平均日射量 (mean values of daily solar radiation; MDSR, MJ m^{-2})，平均栽植期間每日的日輻射量；(11) 生育度日數 (growing degree days; GDD)，為每日的日均溫減去 10℃基礎溫度之總和，GDD 的計算公式如下：

$$GDD = \sum [(T_{max} + T_{min}) / 2 - T_b]$$

T_{max} 為每日最高溫，T_{min} 為每日最低溫，T_b 為基礎溫度 (León Pacheco *et al*. 2019)。當溫度低於 T_b 時，作物生長發育停止。Lai & Huang (2012) 報告顯示，葉菜甘藷在 10–15℃生長呈休眠狀態，且 Wu (2018) 碩士論文調查發現甘藷地上部基礎溫度約為 10℃，因此本試驗基礎溫度設為 10℃。

植體元素分析

本試驗參考 Zarcinas *et al*. (1987) 之方法經修飾後進行，將採收後的紫色葉菜甘藷分別秤取葉片與莖部各 400 g 鮮重，以自來水與去離子水清洗植株，並將植株置入烘箱以 70℃烘乾 48 h。烘乾後植體以鈦刀磨粉機粉碎後進行植體元素分析，氮 (nitrogen, N) 與碳 (carbon, C) 以元素分析儀 (2400 Series II, Perkin Elmer, Waltham, MA, USA) 測定，而磷 (phosphorus, P)、硫 (sulfur, S)、鈉 (sodium, Na)、鉀 (potassium, K)、鈣 (calcium, Ca) 及鎂 (magnesium, Mg) 等元素分析係採用二酸分解法，分別以硝酸 - 過氯酸 (5 : 1，v/v) 與鹽酸進行酸分解，分解液定量並以濾紙 (No.2, Whatman, Little Chalfont, UK) 過濾後，接著以感應耦合電漿原子發射光譜分析儀 (ULTIMA 2C, HORIBA Jobin Yvon, Irvine, CA, USA) 測定，單位以 % 表示。鐵 (iron, Fe)、錳 (manganese, Mn)、硼 (boron, B)、銅 (copper, Cu) 及鋅 (zinc, Zn) 等元素則是利用感應耦合電漿質譜儀 (7500C ICP–MS, Agilent, Santa Clara, CA, USA) 進行測定，單位以 mg kg^{-1} 表示。

統計分析

本研究係採用典型相關分析 (canonical correlation analysis; CCA) (Härdle & Simar 2015)，其為多變量統計的分析方法且係屬交叉共變數矩陣的一種，其目的是探討 2 組變數間相互關係最大的線性組合，並計算 2 組變數在線性關係最大化下的權重。本試驗分析變數包含 24 個不同採收期之氣象資料、8 組生長性狀參數及 14 組植體元素參數。統計分析工具係利用 R 語言，分析過程已初步排除同組變數間所存在的多元共線性現象。

結果與討論

不同採收期對紫色葉菜甘藷生長性狀之影響

本研究於 2016–2018 年利用不同季節定植紫色葉菜甘藷，並獲取 24 個不同採收期的試驗與氣象資料 (表 1 與表 2)。由表 1 結果發現，每季定植後至第一次採收的時間會相較於第二、三次時間較長，可能是扦插苗根系尚未生長所產生的生育延遲現象。再者，隨著採收次數增加則採收所需的天數會逐漸縮短，惟 2016 年 6 月 29 日與 2017 年 6 月 20 日之第三次採收時間相對較長，可能是受 6 月梅雨季節

降雨天數增加，進而影響採收時間點。此外，本研究發現 2017 年 12 月 7 日扦插至第一次採收所需的生育日數長達 81 d，其原因可能是在此生育期間，氣溫低於 15℃的天數約有 21 d，而低溫影響植株根系生長，導致紫色葉菜甘藷生育緩慢。

甘藷原產於熱帶美洲 (Cooley 1951)，其生長適溫為 20–30℃，且在 15℃時以上才開始發根與發芽，若溫度在 10–15℃時生長呈休眠狀態，而 10℃以下易發生寒害，35℃以上則會造成高溫障礙生長衰退，因此甘藷係屬一種暖季作物 (Lai & Huang 2012)。Lee *et al*. (1998) 研究指出，露天栽培之葉菜甘藷由扦插至第一次採收，所需生育日數長短與鮮重生長速度，均顯著受氣象因子影響，而影響生育日數長短的主要限制因子，乃冬季低溫與夏季扦插後，植株生長勢未恢復時的高降雨量。

本研究進一步調查紫色葉菜甘藷 CYY84-67 於 2016–2018 年不同採收期生長性狀，由結果顯示 2017 年 4 月 5 日、9 月 29 日與 2018 年 3 月 30 日、4 月 26 日採收期具有較高的單位面積產量，而上述採收期所栽培的季節主要為春秋兩季 (表 3 與表 4)。為釐清不同採收期氣象資料對紫色葉菜甘藷生長性狀之影響，本試驗分析變數包含 24 個不同採收期之氣象資料與 8 組生長性狀參數。由於變數量較多，本研究係採用典型相關分析 (CCA)，以探討此兩組變數間相關性較大的組合。由表 5 結果發現，生育度日數 (GDD)、累加日射量 (ADSR) 及累加日夜溫差 (ADTR) 可能為影響生長性狀的主要氣象參數，其中第一典型相關變數，以 GDD 與 ADSR 對單枝葉乾重與單枝葉面積的影響權重較大且呈正相關 (r = 0.735)，而在第二典型相關變數，則以 ADSR 與 ADTR 對單枝葉面積與單枝莖乾重的影響權重較高且呈正相關 (r = 0.608)。 已知作物生長與產量會受溫度與太陽輻射量所影響，而作物生育溫度大多以基溫表示，其溫度量化以生育度日數作為估算方法，可用來評估作物生育階段與採收期，以利作物栽培管理 (León Pacheco *et al*. 2019)。本研究利用典型相關分析發現，GDD、ADSR 及 ADTR 可能為影響紫色葉菜甘藷之單枝葉面積、單枝葉乾重及單枝莖乾重的氣象參數，其中又以累加日射量影響權重最大 (表 5)。Wu (2018) 論文顯示，甘藷地上部之基礎溫度約為 10℃，最適生長溫度約為 32℃，且不同品種與採收部位所需的生育度日數也會有所差異。再者，生物量為作物冠層截獲太陽輻射的產物，而作物產量與太陽輻射呈正相關，且增加氮肥含量可提高青花菜與春季油菜之光輻射利用效率，其透過增加葉面積與葉面積指數，以獲得較多的光輻射截獲量，進而提高生物量累積 (VÅgen *et al*. 2004; Fochesatto *et al*. 2016)。此外，日夜溫差的幅度大小也會影響蔬菜的生長、形態及產量 (Myster & Moe 1995; Inthichack *et al*. 2012)。

不同採收期對紫色葉菜甘藷植體元素之消長變化

將 2017–2018 年不同採收期的紫色葉菜甘藷，分別秤取葉片與莖部各 400 g 鮮重進行元素分析，共計 14 種植體元素。在不同採收期葉片的氮含量為 3.1–5.3%、碳含量為 41.7–44.4%、碳氮比 8.4–13.3、磷含量為 0.36–0.57%、硫含量為 0.31–0.42%、鈉含量為 0.10–0.83%、鉀含量為 2.3–4.3%、鈣含量為 1.0–1.9% 及鎂含量為 0.40–0.64% (表 6)，而莖部的氮含量為 0.67–2.29%、碳含量為 38.1–40.9%、碳氮比 17.3–61.4、磷含量為 0.28–0.50%、硫含量為 0.13–0.21%、鈉含量為 0.01–0.35%、鉀含量為 3.8–5.8%、鈣含量為 0.71–1.41% 及鎂含量為 0.22–0.40% (表 7)。另一方面，在不同採收期葉片的鐵含量為 164.4–586.9 mg kg^{-1}、錳含量為 45.3–95.5 mg kg^{-1}、硼含量為 25.4–65.9 mg kg^{-1}、銅含量為 8.2–14.7 mg kg^{-1} 及鋅含量為 18.2–32.0 mg kg^{-1} (表 6)，而莖部的鐵含量為 59.3–347.5 mg kg^{-1}、錳含量為 10.2–18.0 mg kg^{-1}、硼含量為 10.4–27.6 mg kg^{-1}、銅含量為 7.3–13.7 mg kg^{-1} 及鋅含量為 11.7–23.1 mg kg^{-1} (表 7)。

表 2. 紫色葉菜甘藷 CYY84-67 於 2016–2018 年期間 24 個採收期之氣象資料。

Table 2. Meteorological data calculated from 24 cultivation periods of purple leafy sweet potato CYY84-67 in 2016–2018.

Date of transplanting	Date of harvest	ADAT[z]	AMDTAT	AMNTAT	GDD	ADTR	ADSR	MDAT	MMDTAT	MMNTAT	MDTR	MDSR
2016/3/7	2016/4/20	915.1	997.3	844.6	475.1	152.7	500.2	20.8	22.7	19.2	3.5	11.4
	2016/5/17	715.8	770.3	661.2	445.8	109.1	455.0	26.5	28.5	24.5	4.0	16.9
	2016/6/29	1,202.8	1,284.8	1,118.7	772.8	166.1	745.6	28.0	29.9	26.0	3.9	17.3
2016/6/7	2016/7/12	989.5	1,061.6	910.5	639.5	151.1	628.7	28.3	30.3	26.0	4.3	18.0
	2016/8/4	682.0	730.5	627.1	452.0	103.5	482.2	29.7	31.8	27.3	4.5	21.0
	2016/8/24	574.8	611.7	535.7	374.8	76.1	343.7	28.7	30.6	26.8	3.8	17.2
2016/8/30	2016/10/4	963.0	1,038.2	895.4	613.0	142.8	509.6	27.5	29.7	25.6	4.1	14.6
	2016/11/3	807.5	889.4	741.0	507.5	148.5	440.5	26.9	29.6	24.7	4.9	14.7
	2016/11/29	606.6	669.6	556.9	346.6	112.7	305.2	23.3	25.8	21.4	4.3	11.7
2016/12/8	2017/1/24	903.4	1,041.5	798.9	433.4	242.6	569.8	19.2	22.2	17.0	5.2	12.1
	2017/3/1	643.7	753.5	560.3	283.7	193.1	466.6	17.9	20.9	15.6	5.4	13.0
	2017/4/5	702.1	790.5	626.9	352.1	163.6	523.6	20.1	22.6	17.9	4.7	15.0
2017/3/7	2017/4/20	958.7	1,068.0	867.9	518.7	200.1	658.8	21.8	24.3	19.7	4.5	15.0
	2017/5/17	680.9	743.9	620.5	410.9	123.3	434.4	25.2	27.6	23.0	4.6	16.1
	2017/6/20	911.1	973.7	851.5	571.1	122.2	474.2	26.8	28.6	25.0	3.6	13.9
2017/6/28	2017/8/11	1,263.6	1,352.1	1,165.2	823.6	188.4	811.9	28.7	30.7	26.5	4.3	18.5
	2017/9/7	785.8	835.8	733.2	515.8	102.5	490.4	29.1	31.0	27.2	3.8	18.2
	2017/9/29	639.5	693.5	589.5	419.5	104.0	423.9	29.1	31.5	26.8	4.7	19.3
2017/9/5	2017/10/12	1,078.6	1,169.0	996.1	708.6	172.9	676.7	29.2	31.6	26.9	4.7	18.3
	2017/11/9	678.2	744.1	618.1	398.2	126.1	417.3	24.2	26.6	22.1	4.5	14.9
	2017/12/7	628.1	689.2	578.5	348.1	110.7	322.3	22.4	24.6	20.7	4.0	11.5
2017/12/7	2018/2/26	1,379.7	1,567.0	1,236.1	571.0	330.9	869.4	17.0	19.3	15.3	4.1	10.7
	2018/3/30	648.6	730.4	575.5	328.6	154.9	533.0	20.3	22.8	18.0	4.8	16.7
	2018/4/26	639.9	705.9	581.1	369.9	124.8	463.2	23.7	26.1	21.5	4.6	17.2

[z] ADAT: accumulated daily air temperature; AMDTAT: accumulated maximum daytime air temperature; AMNTAT: accumulated minimum nighttime air temperature; GDD: growing degree days (base temperature 10℃); ADTR: accumulated diurnal temperature regimes; ADSR: accumulated daily solar radiation; MDAT: mean values of daily air temperature; MMDTAT: mean values of maximum daytime air temperature; MMNTAT: mean values of minimum nighttime air temperature; MDTR: mean values of diurnal temperature regimes; and MDSR: mean values of daily solar radiation.

表 3. 紫色葉菜甘藷 CYY84-67 於 2016 年定植之不同採收期生長性狀。

Table 3. Comparison of plant growth traits of purple leafy sweet potato CYY84-67 planted in different cultivation periods in 2016.

Date of harvest	Number of terminal buds	Number of leaves per shoot	Leaf area per shoot (cm^2)	Diameter of stem (mm)	Leaf dry weight per shoot (g)	Stem dry weight per shoot (g)	Dry weight of terminal buds (g)	Yield per unit area ($kg\ m^{-2}$)
2016/4/20	4.7 ± 0.5 g[z]	21.5 ± 2.1 e	741.0 ± 87.3 g	4.91 ± 0.08 ef	2.7 ± 0.2 g	1.8 ± 0.1 f	4.5 ± 0.2 f	0.4 ± 0.1 f
2016/5/17	6.8 ± 0.8 fg	28.7 ± 3.7 de	777.9 ± 123.0 g	4.78 ± 0.24 ef	3.3 ± 0.7 g	2.6 ± 0.8 ef	5.9 ± 1.4 ef	0.9 ± 0.3 ef
2016/6/29	8.6 ± 0.4 ef	31.5 ± 1.3 d	869.9 ± 39.2 g	5.22 ± 0.05 abc	3.6 ± 0.2 fg	3.3 ± 0.2 de	7.0 ± 0.3 de	1.4 ± 0.1 def
2016/7/12	9.9 ± 0.3 de	35.5 ± 1.2 d	1,303.9 ± 60.4 ef	5.36 ± 0.14 a	4.8 ± 0.1 cde	4.2 ± 0.2 cd	9.0 ± 0.3 c	2.0 ± 0.1 cde
2016/8/4	9.8 ± 0.2 de	35.1 ± 1.0 d	944.1 ± 26.5 g	5.42 ± 0.08 a	4.3 ± 0.1 ef	3.7 ± 0.2 cd	8.0 ± 0.3 cd	1.9 ± 0.1 def
2016/8/24	11.7 ± 0.8 bcd	42.8 ± 2.6 c	1,440.3 ± 80.5 def	5.21 ± 0.11 abcd	5.0 ± 0.5 cde	3.8 ± 0.4 cd	8.8 ± 0.8 cd	2.6 ± 0.4 bcd
2016/10/4	13.4 ± 1.1 b	52.7 ± 3.9 b	1,615.0 ± 136.1 cd	4.75 ± 0.01 ef	5.3 ± 0.3 cd	4.4 ± 0.3 bc	9.7 ± 0.5 c	3.6 ± 0.5 b
2016/11/3	10.3 ± 1.1 cde	34.3 ± 3.3 d	1,491.5 ± 84.4 cde	5.00 ± 0.10 bcde	5.1 ± 0.5 cde	4.2 ± 0.5 cd	9.2 ± 1.0 c	2.5 ± 0.6 bcd
2016/11/29	12.8 ± 0.2 b	47.1 ± 2.6 bc	1,943.4 ± 116.7 b	4.64 ± 0.04 f	5.4 ± 0.4 c	3.6 ± 0.2 cd	9.0 ± 0.7 c	3.4 ± 0.2 bc
2017/1/24	9.1 ± 0.4 e	31.3 ± 1.0 d	1,212.7 ± 44.3 f	4.92 ± 0.08 def	4.4 ± 0.2 def	3.7 ± 0.2 cd	8.1 ± 0.4 cd	1.7 ± 0.2 def
2017/3/1	12.3 ± 0.7 bc	48.7 ± 1.9 bc	1,709.6 ± 59.8 bc	5.27 ± 0.06 ab	6.5 ± 0.2 b	5.3 ± 0.2 b	11.8 ± 0.4 b	3.6 ± 0.4 b
2017/4/5	20.6 ± 1.6 a	76.7 ± 3.3 a	2,630.6 ± 102.2 a	4.93 ± 0.06 cdef	9.8 ± 0.4 a	8.5 ± 0.4 a	18.2 ± 0.7 a	10.0 ± 1.4 a

[z] Data are mean ± *SE* of flour replicates. Different letters mean significant differences at $P < 0.05$ level by LSD test.

表 4. 紫色葉菜甘藷 CYY84-67 於 2017 年定植之不同採收期生長性狀。

Table 4. Comparison of plant growth traits of purple leafy sweet potato CYY84-67 planted in different cultivation periods in 2017.

Date of harvest	Number of terminal buds	Number of leaves per shoot	Leaf area per shoot (cm^2)	Diameter of stem (mm)	Leaf dry weight per shoot (g)	Stem dry weight per shoot (g)	Dry weight of terminal buds (g)	Yield per unit area ($kg\ m^{-2}$)
2017/4/20	13.3 ± 0.7 de[z]	46.6 ± 3.9 d	1,753.7 ± 140.6 bc	5.26 ± 0.13 bcd	6.1 ± 0.5 de	5.4 ± 0.3 c	11.5 ± 0.8 c	4.0 ± 0.4 bc
2017/5/17	12.4 ± 0.4 de	36.2 ± 0.7 ef	1,381.2 ± 71.3 cd	5.22 ± 0.04 cd	5.1 ± 0.1 ef	5.1 ± 0.1 cd	10.1 ± 0.1 cd	3.2 ± 0.2 c
2017/6/20	11.4 ± 0.1 e	31.4 ± 0.6 f	1,295.1 ± 68.7 de	5.42 ± 0.11 bc	4.6 ± 0.2 fg	4.3 ± 0.2 d	8.8 ± 0.4 de	2.8 ± 0.1 c
2017/8/11	7.1 ± 0.5 f	24.2 ± 1.2 g	908.1 ± 66.9 f	5.59 ± 0.12 ab	3.5 ± 0.1 gh	4.1 ± 0.2 d	7.6 ± 0.3 ef	1.2 ± 0.2 d
2017/9/7	11.7 ± 0.6 e	39.2 ± 2.5 e	1,768.1 ± 208.0 b	5.51 ± 0.13 bc	5.3 ± 0.5 ef	5.7 ± 0.5 bc	11.1 ± 1.0 c	3.4 ± 0.5 c
2017/9/29	17.4 ± 1.0 a	55.5 ± 3.6 bc	2,396.7 ± 137.3 a	5.40 ± 0.07 bc	7.5 ± 0.5 bc	7.1 ± 0.6 a	14.6 ± 1.1 b	6.4 ± 0.7 a
2017/10/12	7.0 ± 0.4 f	20.9 ± 1.9 g	928.9 ± 76.6 ef	5.85 ± 0.06 a	2.9 ± 0.3 h	2.9 ± 0.3 e	5.9 ± 0.5 f	1.1 ± 0.1 d
2017/11/9	14.1 ± 0.3 cd	47.9 ± 0.4 d	1,942.3 ± 179.3 b	5.01 ± 0.14 d	5.7 ± 0.5 ef	4.9 ± 0.3 cd	10.6 ± 0.8 cd	4.1 ± 0.3 bc
2017/12/7	n.d.[y]	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
2018/2/26	14.2 ± 1.0 cd	73.5 ± 3.7 a	2,366.0 ± 137.9 a	4.46 ± 0.11 e	9.3 ± 0.5 a	7.5 ± 0.5 a	16.8 ± 0.9 a	5.3 ± 0.8 ab
2018/3/30	15.5 ± 1.0 bc	61.2 ± 3.3 b	2,323.2 ± 145.4 a	5.20 ± 0.16 cd	8.5 ± 0.5 ab	6.7 ± 0.3 ab	15.2 ± 0.8 ab	5.5 ± 0.6 a
2018/4/26	17.2 ± 0.5 ab	50.9 ± 1.6 cd	2,096.9 ± 129.8 ab	5.01 ± 0.15 d	6.9 ± 0.4 cd	6.7 ± 0.2 ab	13.6 ± 0.5 b	5.9 ± 0.4 a

[z] Data are mean ± *SE* of flour replicates. Different letters mean significant differences at $P < 0.05$ level by LSD test.

[y] n.d. = no data.

表 5.　紫色葉菜甘藷 CYY84-67 生長性狀與氣象參數之典型相關分析。

Table 5. The canonical correlation analysis for plant growth traits of purple leafy sweet potato CYY84-67 with meteorological variables.

Variable	Canonical loading	
	1st	2nd
Climatic factors (x vectors)		
GDD[z]	1.531	0.155
ADSR	-1.569	-1.667
ADTR	0.206	0.939
Growth indices (y vectors)		
Leaf area per single bud	1.121	1.756
Leaf dry weight per single bud	-2.262	0.282
Stem dry weight per single bud	0.064	-2.295
Yield per unit area	0.295	0.542
Canonical correlation (*r*)	0.735	0.608

[z] GDD: growing degree days; ADSR: accumulated daily solar radiation; ADTR: accumulated diurnal temperature regimes.

本試驗分析變數包含 24 個不同採收期之氣象資料與 14 組植體元素參數，並利用典型相關分析 (CCA)，探討不同採收期氣象參數與紫色葉菜甘藷植體元素之相關性組合。由 CCA 結果顯示，GDD、ADSR 及 ADTR 可能為影響葉片植體元素的氣象參數，而葉片植體元素鈣、鎂、鈉、鐵及硫等，可能是受氣象參數所影響的元素；其中第一典型相關變數，以 GDD 對鈣的影響權重較大且呈正相關 (r = 0.856)，在第二典型相關變數，則以 ADSR 對鈉的影響權重較高且呈正相關 (r = 0.704)。另一方面，平均日均溫 (MDAT)、ADSR、ADTR 及 GDD，可能為影響莖部植體元素的氣象參數，其中又以 ADSR 影響權重較大，而莖部植體元素磷、鋅、硫、鐵、錳及鎂等，可能是受氣象參數所影響的元素，在第一典型相關變數之 ADSR、MDAT 及 ADTR 對磷、鋅及硫呈正相關 (r = 0.915)，第二典型相關變數之 ADSR 與 ADTR 對磷、錳及鎂呈正相關 (r = 0.648) (表 8)。

上述研究發現，生育度日數 (GDD)、累加日射量 (ADSR) 及累加日夜溫差 (ADTR) 可能為影響紫色葉菜甘藷植體元素的氣象參數 (表 8)。已知影響植體元素含量變化的因素相當多，除了遺傳特性與肥料施用外，栽植環境的光照、溫度、採收時間及季節等皆是造成植體元素含量波動的原因 (Samuolienė *et al*. 2011; Li *et al*. 2013)。Fallovo *et al*. (2009) 研究指出，高光強度會促進植物對氮、鉀及鎂的吸收，因此夏季採收葉萵苣的氮、鉀及鎂含量會顯著高於春季。另一方面，植物對礦物質的吸收需透過根系呼吸進行主動運輸，而低溫會減少萵苣蒸散量與磷、鉀及硝酸鹽的吸收，若提高根溫則會促進礦物質的吸收量 (Lee *et al*. 2014; Albornoz & Lieth 2015)。

本研究顯示紫色葉菜甘藷 CYY84-67 在春秋兩季會有最高的單位面積產量，利用典型相關分析發現，生育度日數、累加日射量及累加日夜溫差，可能是影響紫色葉菜甘藷之單枝葉面積、單枝葉乾重、單枝莖乾重及植體元素之氣象參數。由於葉菜甘藷生長快速且栽培容易，再加上耐旱耐濕與抗病蟲害等特性，以及農藥施用較少屬於健康蔬菜，尤其適合機械收穫可大面積栽培，惟 CYY84-67 紫葉品系由於適口性不佳，故作為蔬菜供消費者食用的接受度不高。本研究後續將進一步分析不同採收期對紫色葉菜甘藷 CYY84-67 之機能性與抗氧化能力影響變化，據以篩檢出機能性成分含量較高之栽培時期，藉此推廣機能性蔬菜之多元利用性與附加價值，並提供消費者之營養保健參考。

表 6. 紫色葉菜甘藷 CYY84-67 於 2017–2018 年不同採收期之葉片植體元素含量分析。

Table 6. Analysis of plant element contents from the leaves of purple leafy sweet potato CYY84-67 grown in different cultivation periods in 2017–2018.

Date of harvest	Nitrogen (N)	Carbon (C)	C/N ratio	Phosphorus (P)	Sulfur (S)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)
	%					%			
2017/1/24	5.2 ± 0.1 a[z]	44.4 ± 0.6 a	8.5 ± 0.2 g	0.46 ± 0.01 bc	0.41 ± 0.01 ab	0.20 ± 0.02 fg	3.6 ± 0.2 abcd	1.7 ± 0.1 c	0.48 ± 0.02 efg
2017/3/1	4.5 ± 0.1 b	44.1 ± 0.1 ab	9.9 ± 0.3 f	0.47 ± 0.01 bc	0.40 ± 0.02 abc	0.36 ± 0.04 cde	3.4 ± 0.1 bcd	1.8 ± 0.1 abc	0.52 ± 0.02 cde
2017/4/5	4.5 ± 0.2 b	43.6 ± 0.1 abc	9.7 ± 0.3 f	0.45 ± 0.01 bc	0.40 ± 0.03 abc	0.45 ± 0.03 bc	3.5 ± 0.0 bcd	1.9 ± 0.0 a	0.54 ± 0.02 cd
2017/4/20	5.3 ± 0.2 a	44.2 ± 0.2 a	8.4 ± 0.3 g	0.39 ± 0.01 cd	0.41 ± 0.01 ab	0.48 ± 0.07 b	3.0 ± 0.3 cde	1.7 ± 0.0 bc	0.59 ± 0.03 b
2017/5/17	4.2 ± 0.2 bc	42.8 ± 0.2 cde	10.4 ± 0.4 def	0.42 ± 0.02 cd	0.38 ± 0.01 abcd	0.83 ± 0.02 a	2.3 ± 0.1 e	1.8 ± 0.0 abc	0.64 ± 0.02 a
2017/6/20	4.2 ± 0.1 bc	44.4 ± 0.1 a	10.5 ± 0.3 def	0.45 ± 0.01 bc	0.35 ± 0.02 cde	0.38 ± 0.04 bcd	3.0 ± 0.2 de	1.0 ± 0.1 g	0.40 ± 0.01 i
2017/8/11	3.1 ± 0.1 e	41.7 ± 0.4 e	13.3 ± 0.6 a	0.41 ± 0.05 cd	0.31 ± 0.01 e	0.10 ± 0.02 g	3.9 ± 0.1 ab	1.2 ± 0.0 f	0.46 ±0.01 fg
2017/9/7	3.7 ± 0.1 d	44.2 ± 0.3 a	12.1 ± 0.2 bc	0.44 ± 0.01 c	0.34 ± 0.00 de	0.15 ± 0.01 g	3.6 ± 0.1 abcd	1.2 ± 0.1 f	0.41 ± 0.01 hi
2017/9/29	3.9 ± 0.1 cd	42.8 ± 0.8 cde	11.1 ± 0.5 cde	0.55 ± 0.03 a	0.37 ± 0.01 abcde	0.42 ± 0.07 bc	3.5 ± 0.1 bcd	1.4 ± 0.1 e	0.48 ± 0.01 efg
2017/10/12	4.2 ± 0.1 bc	42.1 ± 0.7 de	10.1 ± 0.2 ef	0.45 ± 0.01 bc	0.32 ± 0.04 de	0.28 ± 0.03 ef	4.3 ± 0.1 a	1.2 ± 0.1 f	0.45 ± 0.01 gh
2017/11/9	4.1 ± 0.1 bc	44.3 ± 0.3 a	10.7 ± 0.3 def	0.56 ± 0.04 a	0.38 ± 0.01 abcd	0.45 ± 0.01 bc	3.5 ± 0.2 bcd	1.9 ± 0.1 ab	0.55 ± 0.01 bc
2017/12/7	4.3 ± 0.2 b	42.8 ± 0.2 bcde	10.1 ± 0.6 ef	0.57 ± 0.05 a	0.38 ± 0.03 abcd	0.46 ± 0.03 bc	3.0 ± 0.1 de	1.5 ± 0.1 de	0.47 ± 0.02 efg
2018/2/26	3.5 ± 0.1 de	44.0 ± 0.8 abc	12.5 ± 0.5 ab	0.36 ± 0.01 d	0.35 ± 0.01 cde	0.20 ± 0.03 fg	3.6 ± 0.1 abcd	1.9 ± 0.1 a	0.46 ± 0.01 fg
2018/3/30	3.5 ± 0.2 de	42.1 ± 0.7 de	12.2 ± 0.4 bc	0.45 ± 0.02 bc	0.35 ± 0.02 bcde	0.29 ± 0.00 def	3.8 ± 0.1 abc	1.7 ± 0.1 cd	0.48 ± 0.01 efg
2018/4/26	3.9 ± 0.2 cd	43.1 ± 0.2 abcd	11.3 ± 0.6 cd	0.52 ± 0.04 ab	0.42 ± 0.05 a	0.45 ± 0.03 bc	3.5 ± 0.2 bcd	1.6 ± 0.0 cd	0.50 ± 0.01 def

表 6. 紫色葉菜甘藷 CYY84-67 於 2017–2018 年不同採收期之葉片植體元素含量分析。(續)

Table 6. Analysis of plant element contents from the leaves of purple leafy sweet potato CYY84-67 grown in different cultivation periods in 2017–2018. (Continued)

	Iron (Fe)	Manganese (Mn)	Boron (B)	Copper (Cu)	Zinc (Zn)
Date of harvest			mg kg^{-1}		
2017/1/24	246.3 ± 13.1 efg	45.3 ± 0.6 f	25.8 ± 2.3 f	14.7 ± 0.5 a	32.0 ± 1.0 a
2017/3/1	384.1 ± 21.8 cd	84.2 ± 9.0 ab	53.9 ± 1.5 abc	12.5 ± 0.2 cde	23.8 ± 0.9 defg
2017/4/5	293.8 ± 21.8 def	76.1 ± 7.2 abc	54.9 ± 4.1 abc	12.6 ± 0.8 cde	21.5 ± 1.4 gh
2017/4/20	443.3 ± 60.9 bc	48.8 ± 3.0 ef	40.4 ± 1.4 de	14.6 ± 0.6 ab	29.2 ± 0.4 ab
2017/5/17	586.9 ± 55.5 a	82.0 ± 5.3 ab	48.2 ± 4.4 bcde	12.6 ± 0.3 cde	26.0 ± 0.5 bcdef
2017/6/20	541.5 ± 33.9 ab	47.0 ± 3.3 f	56.6 ± 7.9 ab	11.9 ± 0.5 de	25.2 ± 0.7 cdef
2017/8/11	546.7 ± 92.8 ab	74.2 ± 13.9 bcd	25.4 ± 2.6 f	8.2 ± 0.3 f	18.2 ± 0.4 h
2017/9/7	351.0 ± 32.0 cde	48.2 ± 4.2 f	54.2 ± 2.1 abc	11.0 ± 0.4 e	22.4 ± 1.1 fg
2017/9/29	383.8 ± 43.4 cd	64.9 ± 3.8 bcdef	59.0 ± 4.0 ab	13.9 ± 0.6 abc	28.5 ± 1.2 abc
2017/10/12	289.8 ± 72.7 defg	55.1 ± 11.7 def	39.9 ± 6.4 e	12.9 ± 0.8 bcd	24.3 ± 2.2 defg
2017/11/9	164.4 ± 3.6 g	61.1 ± 7.4 cdef	59.5 ± 4.0 ab	12.5 ± 0.3 cde	27.1 ± 0.8 bcd
2017/12/7	179.5 ± 19.8 fg	47.3 ± 1.4 f	48.5 ± 3.4 bcde	14.1 ± 0.6 abc	26.7 ± 0.9 bcde
2018/2/26	223.9 ± 32.8 fg	68.1 ± 9.8 bcde	44.1 ± 1.8 cde	9.2 ± 0.3 f	23.3 ± 1.4 efg
2018/3/30	278.6 ± 36.1 defg	95.5 ± 5.9 a	52.5 ± 4.5 bcd	11.2 ± 0.7 de	24.1 ± 1.8 defg
2018/4/26	230.9 ± 26.8 efg	72.6 ± 1.6 bcd	65.9 ± 7.1 a	11.5 ± 1.4 de	23.6 ± 2.4 defg

[z] Data are mean ± *SE* of flour replicates. Different letters mean significant differences at $P < 0.05$ level by LSD test.

表 7. 紫色葉菜甘藷 CYY84-67 於 2017–2018 年不同採期之莖部植體元素含量分析。

Table 7. Analysis of plant element contents from the stems of purple leafy sweet potato CYY84-67 grown in different cultivation periods in 2017–2018.

Date of harvest	Nitrogen (N)	Carbon (C)	C/N ratio	Phosphorus (P)	Sulfur (S)	Sodium (Na)	Potassium (K)	Calcium (Ca)	Magnesium (Mg)
	%			%					
2017/1/24	1.95 ± 0.14 b[z]	40.0 ± 0.4 abc	20.8 ± 1.5 gh	0.35 ± 0.01 defg	0.17 ± 0.01 def	0.08 ± 0.01 fghi	4.7 ± 0.2 bcd	1.33 ± 0.12 ab	0.34 ± 0.02 bc
2017/3/1	1.44 ± 0.18 cd	39.6 ± 0.2 abcd	28.6 ± 3.0 efg	0.35 ± 0.01 efg	0.21 ± 0.01 a	0.12 ± 0.01 def	5.8 ± 0.2 a	1.27 ± 0.06 abc	0.33 ± 0.01 bc
2017/4/5	1.71 ± 0.06 bc	40.6 ± 0.3 ab	23.9 ± 0.9 fgh	0.38 ± 0.03 cde	0.20 ± 0.01 abc	0.14 ± 0.01 cde	5.3 ± 0.2 ab	1.41 ± 0.11 a	0.33 ± 0.01 bc
2017/4/20	2.29 ± 0.15 a	39.1 ± 0.2 cde	17.3 ± 1.3 h	0.28 ± 0.01 g	0.15 ± 0.00 fgh	0.16 ± 0.03 bcd	4.7 ± 0.4 bcde	1.21 ± 0.06 bc	0.37 ± 0.02 ab
2017/5/17	1.21 ± 0.11 def	40.9 ± 0.4 a	34.4 ± 2.9 de	0.38 ± 0.02 cde	0.17 ± 0.01 de	0.35 ± 0.03 a	3.9 ± 0.2 f	1.10 ± 0.06 cde	0.40 ± 0.02 a
2017/6/20	1.33 ± 0.04 de	39.5 ± 0.1 abcd	29.8 ± 1.0 efg	0.46 ± 0.03 ab	0.20 ± 0.01 ab	0.18 ± 0.03 bc	4.7 ± 0.3 bcde	1.00 ± 0.03 de	0.32 ± 0.01 c
2017/8/11	0.87 ± 0.03 gh	40.0 ± 0.2 abc	46.4 ± 1.9 b	0.40 ± 0.04 bcde	0.15 ± 0.01 efg	0.01 ± 0.00 j	4.7 ± 0.1 bcde	0.76 ± 0.03 fg	0.23 ± 0.01 de
2017/9/7	0.67 ± 0.07 h	39.9 ± 0.4 abcd	61.4 ± 7.0 a	0.37 ± 0.01 def	0.14 ± 0.00 gh	0.04 ± 0.00 ij	4.3 ± 0.2 cdef	0.73 ± 0.06 fg	0.22 ± 0.01 e
2017/9/29	0.93 ± 0.05 fgh	39.2 ± 0.3 bcde	42.5 ± 1.8 bcd	0.50 ± 0.03 a	0.19 ± 0.00 abc	0.09 ± 0.01 fgh	5.0 ± 0.2 abc	0.91 ± 0.06 ef	0.32 ± 0.01 c
2017/10/12	0.94 ± 0.04 fgh	39.1 ± 0.4 cde	42.0 ± 2.0 bcd	0.33 ± 0.02 efg	0.13 ± 0.01 h	0.08 ± 0.00 fghi	3.8 ± 0.3 f	0.90 ± 0.11 efg	0.32 ± 0.02 c
2017/11/9	1.01 ± 0.14 efg	40.8 ± 0.8 a	43.0 ± 6.0 bcd	0.41 ± 0.02 bcd	0.18 ± 0.01 bcd	0.15 ± 0.01 cde	4.1 ± 0.4 def	1.12 ± 0.07 bcd	0.32 ± 0.03 c
2017/12/7	1.35 ± 0.23 d	38.5 ± 0.7 de	31.3 ± 5.7 ef	0.36 ± 0.04 def	0.21 ± 0.01 a	0.20 ± 0.03 b	4.8 ± 0.3 bcd	1.16 ± 0.07 bcd	0.33 ± 0.01 bc
2018/2/26	0.92 ± 0.05 fgh	38.1 ± 1.1 e	41.8 ± 2.4 bcd	0.31 ± 0.01 fg	0.17 ± 0.00 cde	0.06 ± 0.01 ghi	3.8 ± 0.2 f	1.30 ± 0.08 ab	0.26 ± 0.01 d
2018/3/30	0.91 ± 0.03 fgh	40.5 ± 0.3 abc	44.6 ± 1.4 bc	0.35 ± 0.01 def	0.14 ± 0.00 gh	0.04 ± 0.00 hij	3.9 ± 0.2 ef	0.75 ± 0.01 fg	0.25 ± 0.00 de
2018/4/26	1.19 ± 0.16 defg	39.5 ± 0.5 abcd	34.9 ± 4.2 cde	0.45 ± 0.02 abc	0.20 ± 0.01 ab	0.11 ± 0.01 efg	5.1 ± 0.5 ab	0.71 ± 0.01 g	0.26 ± 0.01 de

表 7. 紫色葉菜甘藷 CYY84-67 於 2017–2018 年不同採期之莖部植體元素含量分析。(續)

Table 7. Analysis of plant element contents from the stems of purple leafy sweet potato CYY84-67 grown in different cultivation periods in 2017–2018. (Continued)

	Iron (Fe)	Manganese (Mn)	Boron (B)	Copper (Cu)	Zinc (Zn)
Date of harvest			mg kg^{-1}		
2017/1/24	85.1 ± 7.7 ef	15.1 ± 1.6 abcd	17.9 ± 1.6 cd	13.7 ± 0.7 a	23.1 ± 2.0 a
2017/3/1	116.8 ± 4.4 def	18.0 ± 1.8 a	11.1 ± 1.4 e	11.1 ± 0.5 bcd	18.9 ± 0.6 b
2017/4/5	161.0 ± 5.7 cde	14.7 ± 0.9 abcd	12.2 ± 2.0 de	13.4 ± 0.7 a	16.9 ± 1.0 b
2017/4/20	190.5 ± 40.2 cd	15.2 ± 1.0 abcd	11.6 ± 0.9 de	11.5 ± 0.1 bc	16.4 ± 0.3 bc
2017/5/17	347.5 ± 87.9 a	16.0 ± 1.9 abc	19.6 ± 2.9 bc	12.3 ± 0.6 ab	17.7 ± 1.2 b
2017/6/20	252.4 ± 40.7 abc	17.4 ± 1.5 ab	27.6 ± 6.2 a	9.8 ± 0.9 cd	12.9 ± 0.8 d
2017/8/11	247.3 ± 39.5 bc	13.0 ± 1.8 cde	19.4 ± 2.8 bc	7.3 ± 0.5 e	11.7 ± 0.6 d
2017/9/7	301.5 ± 63.6 ab	12.5 ± 0.8 cde	15.3 ± 0.7 cde	9.7 ± 0.9 cd	14.0 ± 0.9 cd
2017/9/29	240.8 ± 14.7 bc	13.2 ± 0.8 cde	15.6 ± 1.3 cde	10.4 ± 0.8 cd	17.3 ± 1.3 b
2017/10/12	127.0 ± 19.6 def	12.8 ± 1.3 cde	10.4 ± 1.5 e	9.5 ± 0.5 d	12.2 ± 0.5 d
2017/11/9	59.3 ± 12.7 f	12.0 ± 1.8 de	25.4 ± 1.8 ab	11.0 ± 0.6 bcd	17.4 ± 1.0 b
2017/12/7	69.0 ± 7.3 ef	10.2 ± 1.1 e	20.7 ± 1.5 bc	10.8 ± 0.4 bcd	18.2 ± 0.9 b
2018/2/26	71.1 ± 7.4 ef	13.8 ± 1.6 bcde	17.0 ± 0.6 cde	10.8 ± 0.5 bcd	16.6 ± 1.0 bc
2018/3/30	105.1 ± 13.2 def	15.1 ± 0.5 abcd	12.2 ± 0.7 de	9.7 ± 0.1 d	19.2 ± 0.6 b
2018/4/26	63.7 ± 9.2 ef	11.7 ± 0.6 de	16.0 ± 2.5 cde	9.3 ± 0.6 d	17.0 ± 0.8 b

[z] Data are mean ± *SE* of flour replicates. Different letters mean significant differences at $P < 0.05$ level by LSD test.

表 8. 紫色葉菜甘藷 CYY84-67 不同部位植體元素與氣象參數之典型相關分析。

Table 8. The canonical correlation analysis for plant elements from the leaves and stems of purple leafy sweet potato CYY84-67 with meteorological variables.

Variables	Canonical loadings 1st	Canonical loadings 2nd
The leaves of CYY84-67		
Climatic factors (x vectors)		
GDD[z]	1.148	0.072
ADSR	-0.593	-1.259
ADTR	-0.418	0.274
Nutrition elements (y vectors)		
Calcium (Ca)	-1.238	-0.302
Magnesium (Mg)	0.446	-0.476
Sodium (Na)	0.063	1.135
Sulfur (S)	-0.038	0.441
Iron (Fe)	-0.027	-0.434
Canonical correlation (*r*)	0.856	0.704
The stems of CYY84-67		
Climatic factors (x vectors)		
ADSR	0.847	1.816
MDAT	0.687	-0.894
ADTR	-0.664	-1.255
GDD	-0.124	-0.022
Nutrition elements (y vectors)		
Phosphorus (P)	0.589	-0.586
Zinc (Zn)	-0.554	-0.151
Sulfur (S)	-0.532	-0.175
Iron (Fe)	0.242	-0.229
Manganese (Mn)	-0.165	0.497
Magnesium (Mg)	0.078	-0.662
Canonical correlation (*r*)	0.915	0.648

[z] GDD: growing degree days; ADSR: accumulated daily solar radiation; ADTR: accumulated diurnal temperature regimes; MDAT: mean values of daily air temperature.

引用文獻

Albornoz, F. and J. H. Lieth. 2015. Diurnal macronutrients uptake patterns by lettuce roots under various light and temperature levels. J. Plant Nutr. 38:2028–2043. doi:10.1080/01904167.2015.1009098

Andersen, M. N., T. Heidmann, and F. Plauborg. 1996. The effects of drought and nitrogen on light interception, growth and yield of winter oilseed rape. Acta Agric. Scand. B Soil Plant Sci. 46:55–67. doi:10.1080/09064719609410947

Chen, C. L. 2009. Regulation of crop growth. p.81–89. *in*: Proceedings of the Symposium on Plant Health Management for Flower Crops. (Hsieh, T. F., T. E. Dai, and H. S. Lin, eds.) Spec. Publ. TARI No.143. Taichung, Taiwan. 225 pp. (in Chinese with English abstract)

Chu, Y. H., C. L. Chang, and H. F. Hsu. 2000. Flavonoid content of several vegetables and their antioxidant activity. J. Sci. Food Agric. 80:561–566. doi:10.1002/(SICI)1097-0010(200004)80:5<561::AID-JSFA574>3.0.CO;2-%23

Cooley, J. S. 1951. The sweet potato- Its origin and primitive storage practices. Econ. Bot. 5:378–386. doi:10.1007/BF02984804

Dodd, A. N., J. Kudla, and D. Sanders. 2010. The language of calcium signaling. Ann. Rev. Plant Biol. 61:593–620. doi:10.1146/annurev-arplant-070109-104628

Fallovo, C., Y. Rouphael, M. Cardarelli, E. Rea, A. Battistelli, and G. Colla. 2009. Yield and quality of leafy lettuce in response to nutrient solution composition and growing season. J. Food Agric. Environ. 7:456–462.

Fochesatto, E., A. H. Nied, H. Bergamaschi, G. A. Dalmago, D. G. Pinto, S. Kovaleski, ... J. A. Gouvea. 2016. Interception of solar radiation by the productive structures of spring canola hybrids. Ciênc. Rural 46:1790–1796. doi:10.1590/0103-8478cr20151571

Gunathilake, K. D. P. P. and K. K. D. S. Ranaweera. 2016. Antioxidative properties of 34 green leafy vegetables. J. Funct. Foods 26:176–186. doi:10.1016/j.jff.2016.07.015

Härdle, W. K. and L. Simar. 2015. Canonical correlation analysis. p.443–454. *in*: Applied Multivariate Statistical Analysis. 4th ed. (Härdle, W. K. and L. Simar, eds.) Springer. Berlin, Germany. 580 pp. doi:10.1007/978-3-662-45171-7_16

Inthichack, P., Y. Nishimura, and Y. Fukumoto. 2012. Diurnal temperature alternations affect plant growth, yield and mineral composition in cabbage, lettuce and celery. J. Japanese Soc. Agric. Technol. Manag. 19:37–45. doi:10.20809/seisan.19.2_37

Iqbal, Z., A. G. Memon, A. Ahmad, and M. S. Iqbal. 2022. Calcium mediated cold acclimation in plants: Underlying signaling and molecular mechanisms. Front. Plant Sci. 13:855559. doi:10.3389/fpls.2022.855559

Khader, V. and S. Rama. 1998. Selected mineral content of common leafy vegetables consumed in India at different stages of maturity. Plant Foods Hum. Nutr.

53:71–81. doi:10.1023/a:1008061525579

Kong, Y., J. Masabni, and G. Niu. 2023. Temperature and light spectrum differently affect growth, morphology, and leaf mineral content of two indoor-grown leafy vegetables. Horticulturae 9:331. doi:10.3390/horticulturae9030331

Kurata, R., M. Adachi, O. Yamakawa, and M. Yoshimoto. 2007. Growth suppression of human cancer cells by polyphenolics from sweet potato (*Ipomoea batatas* L.) leaves. J. Agric. Food Chem. 55:185–190. doi:10.1021/jf0620259

Lai, Y. C. and C. L. Huang. 2012. Introduction to the cultivation techniques and varieties of edible sweet potato. p.2–12. *in*: Sweet Potato Health Management Technology and Operation Manual. (Lo, S. F. and Y. C. Lai, eds.) Spec. Publ. TARI No.163. Taichung, Taiwan. 35 pp. (in Chinese)

Lai, Y. C., H. C. Lee, and Y. S. Chen. 2000. Development of leafy sweet potato variety Tainung 71. J. Agric. Res. China 49:14–27. (in Chinese with English abstract) doi:10.29951/JARC.200006.0002

Lee, H. C., B. H. Lee, Y. H. Chen, and F. C. Liu. 1998. Effects of seasonal changes of climate factors on the growth of leafy sweet potato. Chinese J. Agromet. 5:93–100. (in Chinese with English abstract)

Lee, S., J. Jung, J. Sung, S. Ha, D. Lee, T. Kim, and B. Song. 2014. Responses of nutrient uptake, carbohydrates and antioxidants against low temperature in plants. Korean J. Agric. Sci. 41:75–83. doi:10.7744/CNUJAS.2014.41.2.075

León Pacheco, R. I., E. M. Correa Álvarez, J. L. Romero Ferrer, H. Arias Bonilla, J. C. Gómez-Correa, M. J. Yacomelo Hernández, and L. Pérez Artiles. 2019. Accumulation of degree days and their effect on the potential yield of 15 eggplant (*Solanum melongena* L.) accessions in the Colombian Caribbean. Rev. Fac. Nac. Agron. Medellín 72:8917–8926. doi:10.15446/rfnam.v72n3.77112

Li, G., Z. Lin, H. Zhang, Z. Liu, Y. Xu, G. Xu, ... H. Tang. 2019. Anthocyanin accumulation in the leaves of the purple sweet potato (*Ipomoea batatas* L.) cultivars. Molecules 24:3743. doi:10.3390/molecules24203743

Li, S. X., Z. H. Wang, and B. A. Stewart. 2013. Responses of crop plants to ammonium and nitrate N. Adv. Agron. 118:205–397. doi:10.1016/B978-0-12-405942-9.00005-0

Ludvik, B., M. Hanefeld, and M. Pacini. 2008. Improved metabolic control by *Ipomoea batatas* (Caiapo) is associated with increased adiponectin and decreased fibrinogen levels in type 2 diabetic subjects. Diabetes Obes. Metab. 10:586–592. doi:10.1111/j.1463-1326.2007.00752.x

Myster, J. and R. Moe. 1995. Effect of diurnal temperature alternations on plant morphology in some greenhouse crops- A mini review. Sci. Hortic. 62:205–215. doi:10.1016/0304-4238(95)00783-P

Reich, P. B., D. S. Ellsworth, and M. B. Walters. 1998. Leaf structure (specific leaf area) modulates photosynthesis-nitrogen relations: Evidence from within and across species and functional groups. Funct. Ecol. 12:948–958. doi:10.1046/j.1365-2435.1998.00274.x

Rumbaoa, R. G. O., D. F. Cornago, and I. M. Geronimo. 2009. Phenolic content and antioxidant capacity of Philippine sweet potato (*Ipomoea batatas*) varieties. Food Chem. 113:1133–1138. doi:10.1016/j.foodchem.2008.08.088

Samuolienė, G., R. Sirtautas, A. Brazaitytė, A. Viršilė, and P. Duchovskis. 2011. Supplementary red-LED lighting affects phytochemicals and nitrate of baby leaf lettuce. J. Food Agric. Environ. 9:271–274.

Sanders, D., J. Pelloux, C. Brownlee, and J. F. Harper. 2002. Calcium at the crossroads of signaling. Plant Cell 14:S401–S417. doi:10.1105/tpc.002899

Tang, C. C., A. Ameen, B. P. Fang, M. H. Liao, J. Y. Chen, L. F. Huang, ... Z. Y. Wang. 2021. Nutritional composition and health benefits of leaf-vegetable sweet potato in South China. J. Food Compost. Anal. 96:103714. doi:10.1016/j.jfca.2020.103714

VÅgen, I. M., A. O. SkjelvÅg, and H. Bonesmo. 2004. Growth analysis of broccoli in relation to fertilizer nitrogen application. J. Hortic. Sci. Biotechnol. 79: 484-492. doi:10.1080/14620316.2004.11511794

Wang, H., L. Wu, Y. Zhu, and Q. Tao. 2008. Growth, nitrate accumulation, and macronutrient concentration of pakchoi as affected by external nitrate-N: Amino acid-N ratio. J. Plant Nutr. 31:1789–1799. doi:10.1080/01904160802325248

Waterland, N. L., Y. Moon, J. C. Tou, M. J. Kim, E. M. Pena-Yewtukhiw, and S. Park. 2017. Mineral content differs among microgreen, baby leaf, and adult stages in three cultivars of kale. HortScience 52:566–571. doi:10.21273/HORTSCI11499-16

White, P. J. and M. R. Broadley. 2003. Calcium in plants. Ann. Bot. 92:487–511. doi:10.1093/aob/mcg164

Wu, J. Y. 2018. The relation between sweet potato growth stages and thermal units. Master Thesis. Department of Agronomy, National Chung Hsing University. Taichung, Taiwan. 86 pp.

Wurr, D. C. E. and J. R. Fellows. 1991. The influence of solar radiation and temperature on the head weight of crisp lettuce. J. Hortic. Sci. 66:183–190. doi:10.1080/00221589.1991.11516143

Yan, W. and L. A. Hunt. 1999. An equation for model-

ling the temperature response of plants using only the cardinal temperatures. Ann. Bot. 84:607–614. doi:10.1006/anbo.1999.0955

Yoshimoto, M., S. Yahara, S. Okuno, M. S. Islam, K. Ishiguro, and O. Yamakawa. 2002. Antimutagenicity of mono-, di-, and tricaffeoylquinic acid derivatives isolated from sweetpotato (*Ipomoea batatas* L.) leaf. Biosci. Biotechnol. Biochem. 66:2336−2341. doi:10.1271/bbb.66.2336

Zarcinas, B. A., B. Cartwright, and L. R. Spouncer. 1987. Nitric acid digestion and multi-element analysis of plant material by inductively coupled plasma spectrometry. Commun. Soil Sci. Plant Anal. 18:131–146. doi:10.1080/00103628709367806

Effects of Temperature and Solar Radiation on Growth Traits and Plant Elements in Purple Leafy Sweet Potato

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Abstract

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In this study, the purple leafy sweet potato strain CYY84-67 bred by the Chiayi Agricultural Experiment Branch was used in the field experiment from 2016 to 2018 at Taiwan Agricultural Research Institute. A total of 24 different experimental and meteorological data were collected from 3 consecutive harvests in each cultivation period within two years. The objective of this study was to study the effects of temperature and solar radiation on the growth traits and plant elements of purple leafy sweet potato to summarize the optimal cultivation periods for purple leafy sweet potato as well as to clarify the rise and fall of temperature and solar radiation on plant elements. The canonical correlation analysis was adopted to explore the linear relationship between two groups of variables, and the weight of maximizing the correlation between the two sets of variables was calculated. The results of this study showed that purple leafy sweet potato CYY84-67 had the highest yield per unit area in both spring and autumn. The growing degree days (GDD), accumulated daily solar radiation (ADSR), and accumulated diurnal temperature regimes (ADTR) were the major meteorological variables affecting leaf area, dry weight of leaves and stems in purple leafy sweet potato, and ADSR had the greatest weight. In addition, GDD, ADSR, and ADTR also affected plant element contents from the leaves and stems of purple leafy sweet potato CYY84-67. Among these meteorological variables, GDD had the greatest weight on the calcium of the leave, while ADSR had the highest weight on the phosphorus of the stem.

Key words: Purple leafy sweet potato, Temperature, Solar radiation, Growth trait, Plant element.

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研究報告

室內測試 12 種環境友善資材對基徵草蛉 (*Mallada basalis* Walker) 及安平草蛉 (*Mallada desjardinsi* Navás) 之影響

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摘要

董耀仁、許北辰。2024。室內測試 12 種環境友善資材對基徵草蛉 (*Mallada basalis* Walker) 及安平草蛉 (*Mallada desjardinsi* Navás) 之影響。台灣農業研究 73(1):53–62。

本研究於室內以浸泡方式測試 10% 香茅精油微乳劑 (黴挫)、乳化葵花油、中和亞磷酸、石灰硫磺合劑、波爾多液、碳酸氫鉀、36% 肉桂精油微乳劑 (黑修羅)、40% 肉桂精油微乳劑 (炭無踪)、植物油混方、苦楝油、窄域油及蘇力菌等 12 種生物農藥/免登記植物保護資材，對基徵草蛉 (*Mallada basalis* Walker) 與安平草蛉 (*Mallada desjardinsi* Navás) 的卵、幼蟲、蛹及成蟲之影響。試驗結果顯示 10% 香茅精油微乳劑、中和亞磷酸、波爾多液、碳酸氫鉀、36% 肉桂精油微乳劑、40% 肉桂精油微乳劑、植物油混方及蘇力菌等 8 種環境友善資材，對2種草蛉卵、幼蟲、蛹及成蟲均無不利影響；然而窄域油、苦楝油、乳化葵花油及石灰硫磺合劑，對 2 種草蛉之卵、1 齡幼蟲及蛹，顯著造成較對照組高之死亡率。基徵草蛉為政府補助農友購買天敵項目之一，而市售商品以卵片與幼蟲為主。依本試驗結果，農友於田區施用窄域油、苦楝油、乳化葵花油及石灰硫磺等資材時，要避免噴施到釋放的草蛉卵片與幼蟲。

關鍵詞：基徵草蛉、安平草蛉、環境友善資材、整合防治。

前言

隨著人口快速增加，預計到 2050 年，人類對糧食的需求將急劇增加，須增加農業生產才能滿足這種需求。研究表明，增加作物產量與更好地管理所生產的作物，並不擴大土地，才是確保不斷增長的人口能獲得充足糧食供應的最佳途徑 (Fróna *et al*. 2019)。然而氣候變遷所導致的全球暖化、頻繁乾旱、二氧化碳濃度變化及其他氣候相關變數等因素持續對作物產量構成重大威脅 (Lin *et al*. 2022)。面臨氣候變遷所帶來的蟲害問題，廣食性捕食者 (generalist predator) 因其可適應的寄主範圍廣，與專一性捕食者 (specialist predator) 相比，較能克服因氣候條件改變所導致與昆蟲食餌發生不一致的問題，也因此被認為更能抵抗氣候變遷帶來的影響 (Selvaraj *et al*. 2013)。

草蛉屬於脈翅目 (Neuroptera) 草蛉科 (Chrysopidae) 昆蟲，可捕食蚜蟲、粉蝨、薊馬、葉蟎、粉介殼蟲及鱗翅目等昆蟲的卵與初齡幼蟲 (Li *et al*. 2011; Hsu & Lu 2020)，是一種廣食性捕食者。在臺灣基徵草蛉 (*Mallada basalis* Walker) 幼蟲已應用在防治草莓、網室木瓜、棗樹及柑桔等作物害蟲 (Lu & Su 2005)，而安平草蛉 (*Mallada desjardinsi* Navás) 除曾應用於防治桑木蝨 (*Paurocephala psylloptera* Crawford) (Chang 2000) 外，其幼蟲亦可捕食粉介殼蟲 (*Maconellicoccus hirsutus* Green)、菸草粉蝨 (*Bemisia tabaci* Gennadius)、棉鈴蟲 (*Helicoverpa armigera* Hubner)、斜紋夜蛾 (*Spodoptera litura* Fabricius) 與 *Earias vittella* (Fabricius) 等夜蛾之初齡幼蟲、棉蚜 (*Aphis gossypii* Glover)、偽菜蚜 (*Lipaphis erysimi*

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Kalt)、菜蚜 (*Brevicoryne brassicae* Linnaeus) 及 *Uroleucon carthami* (Hille Ris Lambers) 等蚜蟲與茶紅蜘蛛 (*Oligonychus coffeae* Nietner) 等作物有害生物 (Boopathi *et al*. 2016)，以上二者為臺灣農業環境中的重要捕食性天敵 (Lu & Wang 2006; Hsu & Lu 2020)。

目前國內並無施用生物農藥/免登記植物保護資材對草蛉影響之詳細研究，為此本研究以基徵草蛉與安平草蛉卵、幼蟲、蛹及成蟲為試驗材料，測試施用10%香茅精油微乳劑 (黴挫，Mold Stop)、乳化葵花油 (emulsified sunflower oil)、中和亞磷酸 (neutralized phosphorous acid)、石灰硫磺合劑 (lime sulfur mixture)、波爾多液 (Bordeaux mixture)、碳酸氫鉀 (potassium bicarbonate)、36% 肉桂精油微乳劑 (黑修羅，Black Shura)、40% 肉桂精油微乳劑 (炭無踪，Anthracnose Escape)、植物油混方 (plant oils mixture)、苦楝油 (neem oil)、窄域油 (narrow range oil) 及蘇力菌 (*Bacillus thuringiensis*) 等 12 種生物農藥/免登記植物保護資材 (https://www.afa.gov.tw/cht/index.php?code=list&ids=353&mod_code=view&a_id=405)，對基徵草蛉與安平草蛉之卵、幼蟲、蛹及成蟲之影響。

材料與方法

本研究所需草蛉與植物油混方，由農業部農業試驗所 (以下簡稱農試所) 應用動物組農業昆蟲整合管理與應用研究室提供。10% 香茅精油微乳劑 (商品名『黴挫』，Mold Stop，農試所配方)、乳化葵花油、36% 肉桂精油微乳劑 (商品名『黑修羅』，Black Asura，農試所配方)、碳酸氫鉀及 40% 肉桂精油微乳劑 (商品名『炭無蹤』，Anthracnose Escape，農試所配方) 由農試所植物病理組真菌研究室提供 (Lin *et al*. 2020)，中和亞磷酸、石灰硫磺合劑、波爾多液及碳酸氫鉀等原料與試驗操作所需材料設備均購自振詠興業公司 (臺灣臺中市) 後，自行調配後供試驗使用，苦楝油 (95%) 購自興農股份有限公司 (臺灣臺中市)、窄域油 (99%) 購自玉田地有限公司 (臺灣苗栗縣)、蘇力菌 (48.1%, *B. thuringiensis aizawai* ABTS-1857) 購自立農化學股份有限公司 (臺灣雲林縣)。

於室內 (控溫實驗室，溫度 25 ± 1℃，光照 12 h，濕度 60 ± 5 RH%) 測試 12 種環境友善資材對基徵草蛉與安平草蛉之影響，各試驗資材之濃度選定，以原資材之推薦使用濃度為低濃度組別，其 2 倍濃度為高濃度組別 (使用試驗資材與濃度詳如表 1)。為確保能與資材充分接觸，分別將單一基徵草蛉與安平草蛉之卵 (< 1 d)、1 齡幼蟲 (< 1 d)、2 齡幼蟲 (< 1 d)、3 齡幼蟲 (< 1 d)、蛹 (< 1 d) 及雌成蟲 (< 1 d) 及雄成蟲 (< 1 d) 放入聚乙烯材質之 32 目束口網袋 (15 cm × 10 cm) 中後，將網袋浸於各處理資材溶液中，輕輕擾動 2–3 s 後，將網袋內的各試驗標的取出後，各自單獨放置於透明塑膠養蟲盒 (9.5 cm × 5.5 cm) 中，養蟲盒內提供飼料與水，每日觀察記錄卵的孵化情況與蛹的羽化情況，各齡期幼蟲與雌、雄成蟲死亡情況，卵經處理後觀察並記錄至幼蟲孵化前之死亡率；蛹經處理後觀察至成蟲羽化前之死亡率；成蟲經處理後觀察 3 d 間之死亡率，以浸水處理為對照組，本試驗每組任取 10 隻幼蟲作死亡率測試，各組試驗處理進行 5 重複。

試驗所得各項資料，卵、各齡期幼蟲、蛹及雌、雄成蟲之死亡率，先以 SAS-EG (Version 7.1) 統計分析軟體，經常態性檢定符合常態分布後，再進行變方分析 (analysis of variance; ANOVA)，並以最小顯著差異性測驗 (least significant difference test; LSD test) 分析其差異顯著性。

結果

本試驗在友善環境資材對兩種草蛉卵期影響結果，顯示低與高濃度之窄域油，對基徵草蛉的卵均顯著較對照組有較高之死亡率；而於安平草蛉組別，低與高濃度之窄域油、苦楝油，及石灰硫磺，以及高濃度之乳化葵花油，均顯著較對照組有較高之死亡率。其餘中和亞磷酸等 8 種試驗資材，不論施用低濃度或高濃度，對基徵草蛉與安平草蛉卵的死亡率，均無不利影響 (表 2)。而對不同齡期幼蟲之影響試驗結果顯示，僅低與高濃度窄域油對基徵草蛉

1 齡幼蟲，與高濃度窄域油對安平草蛉 1 齡幼蟲，均顯著較對照組有較高之死亡率，但對 2 與 3 齡幼蟲皆無不利影響。其餘 11 種試驗資材對基徵草蛉與安平草蛉其 2 與 3 齡幼蟲均無不利影響 (表 3 至表 5)。

各種資材對兩種草蛉蛹期之影響試驗結果

表 1. 各試驗資材使用濃度。

Table 1. The concentration of each test material used.

	Testing concentration[z]	
Name of material	Low concentration	High concentration
Lime sulfur mixture	500×	250×
Neutralized phosphorous acid	500×	250×
Bordeaux mixture	250×	125×
Potassium bicarbonate	500×	250×
Black Shura	1,000×	500×
Anthracnose Escape	1,000×	500×
Mold Stop	500×	250×
Plant oils mixture	200×	100×
Emulsified sunflower oil	200×	100×
Neem oil	200×	100×
Narrow range oil	400×	200×
Bacillus thuringiensis	1,000×	500×

[z] Dilution ratio, low concentration according to recommended concentration, high concentration using 2 times recommended concentration.

表 2. 12 種試驗資材對基徵草蛉 (*Mallada basalis* Walker) 與安平草蛉 (*Mallada desjardinsi* Navás) 卵之影響。

Table 2. Effect of 12 test materials on *Mallada basalis* Walker and *Mallada desjardinsi* Navás eggs[z].

	Mean mortality (± *SE*)			
	M. basalis Walke		*M. desjardinsi* Navás	
Treatments	Low concentration	High concentration	Low concentration	High concentration
Lime sulfur mixture	22.0 (5.9) b	26.0 (6.3) b	26.0 (6.3) b	32.0 (6.7) bc
Neutralized phosphorous acid	12.0 (4.6) b	14.0 (5.0) b	14.0 (5.0) bc	16.0 (5.2) cde
Bordeaux mixture	20.0 (5.7) b	28.0 (6.4) b	22.0 (5.9) bc	26.0 (6.3) bcde
Potassium bicarbonate	22.0 (5.9) b	24.0 (6.1) b	18.0 (5.5) bc	20.0 (5.7) cde
Black Shura	14.0 (5.0) b	16.0 (5.2) b	12.0 (4.6) bc	14.0 (5.0) de
Anthracnose Escape	14.0 (5.0) b	18.0 (5.5) b	12.0 (4.6) bc	14.0 (5.0) de
Mold Stop	12.0 (4.6) b	14.0 (5.0) b	18.0 (5.5) bc	20.0 (5.7) cde
Plant oils mixture	16.0 (5.2) b	20.0 (5.7) b	18.0 (5.5) bc	20.0 (5.7) cde
Emulsified sunflower oil	26.0 (6.3) ab	28.0 (6.4) b	20.0 (5.7) bc	30.0 (6.5) bcd
Bacillus thuringiensis	12.0 (4.6) b	14.0 (5.0) b	14.0 (5.0) bc	12.0 (4.6) e
Neem oil	22.0 (5.9) b	26.0 (6.3) b	26.0 (6.3) b	38.0 (6.9) b
Narrow range oil	38.0 (6.9) a	48.0 (7.1) a	46.0 (7.1) a	64.0 (6.9) a
Control	12.0 (4.6) b	12.0 (4.6) b	10.0 (4.3) c	10.0 (4.3) e

[z] For each column, means followed by the same letter are not significantly different at $P < 0.05$ (Fisher's protected least significant difference test).

表 3. 12 種試驗資材對基徵草蛉 (*Mallada basalis* Walker) 與安平草蛉 (*Mallada desjardinsi* Navás) 其 1 齡幼蟲之影響。

Table 3. Effect of 12 test materials on *Mallada basalis* Walker and *Mallada desjardinsi* Navás first instar larvae[z].

	Mean mortality (± *SE*)			
	M. basalis Walke		*M. desjardinsi* Navás	
Treatments	Low concentration	High concentration	Low concentration	High concentration
Lime sulfur mixture	0.0 (0.0) b	4.0 (2.8) b	0.0 (0.0) a	0.0 (0.0) b
Neutralized phosphorous acid	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) a	0.0 (0.0) b
Bordeaux mixture	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) a	0.0 (0.0) b
Potassium bicarbonate	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) a	0.0 (0.0) b
Black Shura	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) a	0.0 (0.0) b
Anthracnose Escape	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) a	0.0 (0.0) b
Mold Stop	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) a	0.0 (0.0) b
Plant oils mixture	0.0 (0.0) b	4.0 (2.8) b	0.0 (0.0) a	0.0 (0.0) b
Emulsified sunflower oil	0.0 (0.0) b	4.0 (2.8) b	0.0 (0.0) a	0.0 (0.0) b
Bacillus thuringiensis	0.0 (0.0) b	2.0 (2.0) b	0.0 (0.0) a	0.0 (0.0) b
Neem oil	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) a	0.0 (0.0) b
Narrow range oil	10.0 (4.3) a	22.0 (5.9) a	0.0 (0.0) a	26.0 (6.3) a
Control	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) a	0.0 (0.0) b

[z] For each column, means followed by the same letter are not significantly different at $P < 0.05$ (Fisher's protected least significant difference test).

表 4. 12 種試驗資材對基徵草蛉 (*Mallada basalis* Walker) 與安平草蛉 (*Mallada desjardinsi* Navás) 其 2 齡幼蟲之影響。

Table 4. Effect of 12 test materials on *Mallada basalis* Walker and *Mallada desjardinsi* Navás second instar larvae[z].

	Mean mortality (± *SE*)			
	M. basalis Walke		*M. desjardinsi* Navás	
Treatments	Low concentration	High concentration	Low concentration	High concentration
Lime sulfur mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Neutralized phosphorous acid	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Bordeaux mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Potassium bicarbonate	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Black Shura	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Anthracnose Escape	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Mold Stop	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Plant oils mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Emulsified sunflower oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Bacillus thuringiensis	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Neem oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Narrow range oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Control	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a

[z] For each column, means followed by the same letter are not significantly different at $P < 0.05$ (Fisher's protected least significant difference test).

表 5. 12 種試驗資材對基徵草蛉 (*Mallada basalis* Walker) 與安平草蛉 (*Mallada desjardinsi* Navás) 其 3 齡幼蟲之影響。

Table 5. Effect of 12 test materials on *Mallada basalis* Walker and *Mallada desjardinsi* Navás third instar larvae[z].

	Mean mortality (± *SE*)			
	M. basalis Walke		*M. desjardinsi* Navás	
Treatments	Low concentration	High concentration	Low concentration	High concentration
Lime sulfur mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Neutralized phosphorous acid	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Bordeaux mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Potassium bicarbonate	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Black Shura	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Anthracnose Escape	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Mold Stop	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Plant oils mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Emulsified sunflower oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Bacillus thuringiensis	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Neem oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Narrow range oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Control	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a

[z] For each column, means followed by the same letter are not significantly different at $P < 0.05$ (Fisher's protected least significant difference test).

顯示，僅低濃度與高濃度之窄域油，對基徵草蛉與安平草蛉之蛹，顯著較對照組有較高之死亡率；而高濃度苦楝油對基徵草蛉與安平草蛉之蛹，與低濃度苦楝油對安平草蛉蛹，均顯著較對照組有較高之死亡率 (表 6)。對成蟲期之影響試驗結果顯示，不論以低濃度或高濃度處理，所有資材對基徵草蛉與安平草蛉的雌、雄成蟲均無不利影響 (表 7 與表 8)。

討論

作物的永續生產與農業環境管理所面臨的重大挑戰，包括氣候變遷、資源匱乏及生態環境退化。其中植物病害、蟲害及雜草危害所造成的農作物損失更是嚴重影響糧食生產 (Pretty & Bharucha 2015)。害蟲整合管理技術除可減少化學合成農藥對環境所帶來的不利影響、穩定糧食供應及農業生態環境，還可降低防治成本來提升農業收益。而在害蟲整合管理中，生物防治技術為其中之一項重要的害蟲防治技術 (Angon *et al*. 2023; Raut *et al*. 2023)。昆蟲綱中有超過 30 個科的分類群，是農業害蟲重要捕食性天敵，包括瓢蟲科 (Coccinellidae)、草蛉科 (Chrysopidae)、隱翅蟲科 (Staphylinidae)、花椿科 (Anthocoridae)、食蚜蠅科 (Syrphidae)、癭蚋科 (Cecidomyiidae)、獵椿科 (Reduviidae)、步行蟲科 (Carabidae) 及蟻科 (Formicidae)，這些捕食性昆蟲的成蟲或幼蟲 (若蟲) 可捕食蚜蟲、粉蝨、薊馬、介殼蟲及鱗翅目蛾類的卵與幼蟲，在永續農業的害蟲管理上發揮重大的作用 (Seni & Halder 2022)，而草蛉科的草蛉即為重要農作物害蟲天敵，同時基徵草蛉亦是我國補助農友購買的害蟲天敵 (https://www.aphia.gov.tw/ws.php?id=21989)。害蟲整合管理透過使用數種害蟲防治技術，以降低化學合成農藥的使用，是一種可持續的害蟲管理方法 (Dara 2019)。為降低化學合成農藥風險，我國政府除補助生物防治天敵外，亦針對生物農藥與免登記植物保護資材進行補助，惟此類生物農藥

表 6. 12 種試驗資材對基徵草蛉 (*Mallada basalis* Walker) 與安平草蛉 (*Mallada desjardinsi* Navás) 其蛹之影響。

Table 6. Effect of 12 test materials on *Mallada basalis* Walker and *Mallada desjardinsi* Navás pupae[z].

	Mean mortality (± *SE*)			
	M. basalis Walke		*M. desjardinsi* Navás	
Treatments	Low concentration	High concentration	Low concentration	High concentration
Lime sulfur mixture	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) c
Neutralized phosphorous acid	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) c
Bordeaux mixture	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) c
Potassium bicarbonate	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) c
Black Shura	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) c
Anthracnose Escape	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) c
Mold Stop	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) c
Plant oils mixture	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) c
Emulsified sunflower oil	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) c
Bacillus thuringiensis	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) c
Neem oil	2.0 (2.0) ab	6.0 (3.4) a	4.0 (2.8) a	10.0 (4.3) b
Narrow range oil	4.0 (2.8) a	8.0 (3.9) a	6.0 (3.4) a	16.0 (5.2) a
Control	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) b	0.0 (0.0) c

[z] For each column, means followed by the same letter are not significantly different at $P < 0.05$ (Fisher's protected least significant difference test).

表 7. 12 種試驗資材對基徵草蛉 (*Mallada basalis* Walker) 成蟲之影響。

Table 7. Effect of 12 test materials on *Mallada basalis* Walker adult[z].

	Mean mortality (± *SE*)			
	M. basalis Walke female		*M. desjardinsi* Navás male	
Treatments	Low concentration	High concentration	Low concentration	High concentration
Lime sulfur mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Neutralized phosphorous acid	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Bordeaux mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Potassium bicarbonate	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Black Shura	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Anthracnose Escape	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Mold Stop	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Plant oils mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Emulsified sunflower oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Bacillus thuringiensis	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Neem oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Narrow range oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Control	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a

[z] For each column, means followed by the same letter are not significantly different at $P < 0.05$ (Fisher's protected least significant difference test).

表 8. 12 種試驗資材對安平草蛉 (*Mallada desjardinsi* Navás) 成蟲之影響。

Table 8. Effect of 12 test materials on *Mallada desjardinsi* Navás adult[z].

	Mean mortality (± *SE*)			
	M. basalis Walke female		*M. desjardinsi* Navás male	
Treatments	Low concentration	High concentration	Low concentration	High concentration
Lime sulfur mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Neutralized phosphorous acid	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Bordeaux mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Potassium bicarbonate	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Black Shura	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Anthracnose Escape	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Mold Stop	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Plant oils mixture	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Emulsified sunflower oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Bacillus thuringiensis	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Neem oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Narrow range oil	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
Control	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a

[z] For each column, means followed by the same letter are not significantly different at $P < 0.05$ (Fisher's protected least significant difference test).

與免登植物保護資材對害蟲天敵之影響，迄今目前尚無詳細的研究。

前人研究顯示，施用油類資材對草蛉可能有不利影響，Schuster & Stansly (2000) 測試施用石蠟油對 *Chrysoperla rufilabris* (Burmeister) 與 *Ceraeochrysa cubana* (Hagen) 2 種草蛉其卵、幼蟲及成蟲的影響，結果顯示施用濃度 0.5%、1% 及 2%，其卵的死亡率分別為 96%、95% 及 98%；2 齡幼蟲死亡率為 9%、9% 及 4%；成蟲死亡率則為 12%、16% 及 12%，以上顯示對草蛉的卵期影響最大，與本試驗結果類似，施用窄域油對基徵草蛉與安平草蛉卵造成的死亡率亦是最高，而乳化葵花油高濃度施用於安平草蛉的卵，也有相似情形 (表 2 與表 3)。Khan *et al*. (2015) 將苦楝油噴施於番茄葉片後，測試處理經 0、3、7 及 14 d 後之苦楝油噴施番茄葉片，其殘效對 *Chrysoperla carnea* (Stephens) 草蛉的卵、幼蟲、蛹及成蟲死亡率之影響，結果顯示對草蛉的卵與蛹分別造成 65% 與 62.5% 死亡率，然而本試驗中施用苦楝油雖對安平草蛉卵有不利影響，但對基徵草蛉的卵則無影響；高濃度苦楝油對基徵草蛉與安平草蛉之蛹同樣有不利影響，而低濃度苦楝油則僅對安平草蛉之蛹有不利影響，雖然本試驗結果同樣顯示接觸苦楝油，對草蛉卵與蛹可能有不利影響，但會因使用濃度與草蛉種類而呈現不同結果 (表 2 與表 6)。灰硫礦以往廣泛作為殺真菌劑、殺蟲劑及殺蟎劑使用 (Wearing *et al*. 2010)，且往昔研究中已知其對寄生蜂與捕植蟎等多種生物天敵具有不利影響 (Newman *et al*. 2004; Vacacela Ajila *et al*. 2020)，Venzon *et al*. (2013) 將辣椒葉噴施不同濃度石灰硫礦後，接上 1 隻初孵化的 *Chrysoperla externa* Hagen 草蛉幼蟲，觀察其發育至成蟲比率，試驗結果顯示當草蛉幼蟲接觸經稀釋 100 倍的石灰硫礦噴施後葉片，僅有 50% 的幼蟲可發育至成蟲，顯示接觸石灰硫礦對草蛉幼蟲可能有不利影響。而本研究結果顯示，浸泡石灰硫礦對基徵草蛉與安平草蛉不同齡期幼蟲、蛹及成蟲，並無不利影響，與對照組相較無顯著差異；但對於安平草蛉的卵，不論是浸泡低濃度或高

濃度石灰硫磺均有不利影響，顯示石灰硫磺對草蛉的影響可能會因種類、發育階段及施用方式有所不同 (表 2 至表 8)。

研究顯示害蟲整合管理的成功要件之一，是選用對天敵傷害小的友善資材，於控制害蟲時同時保有田間天敵族群 (Chen *et al*. 2009)。本研究測試之各項環境友善資材，為農試所長年研發，且已於田間測試並進行技轉程序，資材中屬精油配方者，為確認供試品皆具有同等效力，本研究皆採用實驗室提供之穩定可靠樣品，惟未完成技術轉移者尚無法提供詳細成分說明，亦無正式發表文獻報告。本研究先測定這些資材對草蛉各期存活率之影響，期望作為後續田間應用時，對環境中昆蟲天敵影響之參考依據。

我國政府推動化學農藥風險十年減半政策，其中核心之一為強化整合管理並鼓勵友善農業的管理策略，政府並針對農友推出購買生物天敵與生物農藥/免登記植物保護資材補助。基徵草蛉為政府補助農友購買之生物天敵，廠商販售之草蛉商品為卵片或幼蟲，根據本試驗結果，農友於田區施用窄域油、苦楝油、乳化葵花油及石灰硫磺等生物農藥/免登記植物保護資材時，要注意施用資材種類及濃度，同時避免施用到釋放的草蛉卵片與幼蟲。

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引用文獻

Angon, P. B., S. Mondal, I. Jahan, M. Datto, U. B. Antu, F. J. Ayshi, and Md. S. Islam. 2023. Integrated pest management (IPM) in agriculture and its role in maintaining ecological balance and biodiversity. Adv. Agric. 2023:5546373. doi:10.1155/2023/5546373

Boopathi, T., S. B. Singh, M. Ravi, and T. Manju. 2016. Distribution and biology of *Mallada desjardinsi* (Neuroptera: Chrysopidae) in India and its predatory potential against *Aleurodicus dispersus* (Hemiptera: Aleyrodidae). J. Econ. Entomol. 109:1988–1994. doi:10.1093/jee/tow154

Chang, C. P. 2000. Investigation on the life history of *Mallada basalis* (Walker) (Neuroptera: Chrysopidae) and the effects of temperatures on its development. Formosan Entomol. 20:73–87. (in Chinese with English abstract) doi:10.6660/TESFE.2000009

Chen, C., J. Zheng, J. Xie, X. Xie, and R. Mao. 2009. Pest management based on petroleum spray oil in navel orange orchard in Ganzhou, South China. J. Pest Sci. 82:155–162. doi:10.1007/s10340-008-0234-9

Dara, S. K. 2019. The new integrated pest management paradigm for the modern age. J. Integr. Pest Manag. 10:12. doi:10.1093/jipm/pmz010

Fróna, D., J. Szenderák, and M. Harangi-Rákos. 2019. The challenge of feeding the world. Sustainability 11:5816. doi:10.3390/su11205816

Hsu, P. C. and C. T. Lu. 2020. An improved core-shell microcapsule diet for rearing larvae of *Mallada basalis* (Neuroptera: Chrysopidae). Pest Manag. Sci. 76:1121–1127. doi:10.1002/ps.5624

Khan, S. Z., F. Ullah, S. Khan, M. A. Khan, and M. A. Khan. 2015. Residual effect of insecticides against different stages of green lacewing, *Chrysoperla Carnea* (Neuroptera: Chrysopidae). J. Entomol. Zool. Stud. 3(4):114–119.

Li, S. Q., S. S. Huang, S. C. Han, Z. G. Li, J. W. Ye, and Y. J. Zhang. 2011. Impact of low-temperature refrigeration on the eggs and pupal development of *Mallada* sp. J. Environ. Entomol. 33:478–481. (in Chinese with English abstract)

Lin, C. P., J. N. Tsai, T. F. Hsieh, and P. J. Ann. 2020. Chemical screening and field trials for controlling pitaya flower wet rot caused by Gilbertella persicaria. J. Taiwan Agric. Res. 69:207–217. (in Chinese with English abstract) doi:10.6156/JTAR.202009_69(3).0003

Lin, H. I., Y. Y. Yu, F. I. Wen, and P. T. Liu. 2022. Status of food security in east and Southeast Asia and challenges of climate change. Climate 10:40. doi:10.3390/cli10030040

Lu, C. T. and T. H. Su. 2005. Effect of low-temperature storage of eggs on the biological characters of *Mallada basalis* (Neuroptera: Chrysopidae). Plant Prot. Bull. 47:1–14. (in Chinese with English abstract) doi:10.6715/PPB.200503_47(1).0001

Lu, C. T. and C. L. Wang. 2006. Control effect of *Mallada basalis* on insect pests of nethouse sweet peppers. J. Taiwan Agric. Res. 55:111–120. (in Chinese with English abstract) doi:10.6156/JTAR/2006.05502.04

Newman, I. C., J. T. S. Walker, and D. J. Rogers. 2004. Mortality of the leafroller parasitoid *Dolichogenidea*

tasmanica (Hym: Braconidae) exposed to orchard pesticide residues. N. Z. Plant Prot. 57:8–12.

Pretty, J. and Z. P. Bharucha. 2015. Integrated pest management for sustainable intensification of agriculture in Asia and Africa. Insects 6:152–182. doi:10.3390/insects6010152

Raut, A. M., A. N. Banu, W. Akram, R. S. Nain, K. Singh, J. Wahengabam, ... M. A. Shah. 2023. Impact of pesticides on diversity and abundance of predatory arthropods in rice ecosystem. Appl. Environ. Soil Sci. 2023:8891070. doi:10.1155/2023/8891070

Schuster, D. J. and P. A. Stansly. 2000. Response of two lacewing species to biorational and broad-spectrum insecticides. Phytoparasitica 28:297–304. doi:10.1007/BF02981824

Selvaraj, S., P. Ganeshamoorthi, and T. Pandiaraj. 2013. Potential impacts of recent climate change on biological control agents in agro-ecosystem: A review. Int. J. Biodivers. Conserv. 5:845–852. doi:10.5897/IJBC2013.0551

Seni, A. and J. Halder. 2022. Role of predators in insect pests management for sustainable agriculture. Agric. Lett. 2(2):42–45.

Vacacela Ajila, H. E., E. E. Oliveira, F. Lemos, K. Haddi, F. Colares, P. H. Marques Gonçalves, ... A. Pallini. 2020. Effects of lime sulfur on *Neoseiulus californicus* and *Phytoseiulus macropilis*, two naturally occurring enemies of the two-spotted spider mite *Tetranychus urticae*. Pest Manag. Sci. 76:996–1003. doi:10.1002/ps.5608

Venzon, M., R. M. Oliveira, A. L. Perez, F. A. Rodríguez-Cruz, and S. Martins Filho. 2013. Lime sulfur toxicity to broad mite, to its host plants and to natural enemies. Pest Manag. Sci. 69:738–743. doi:10.1002/ps.3431

Wearing, C. H., B. A. Attfield, and K. Colhoun. 2010. Biological control of woolly apple aphid, *Eriosoma lanigerum* (Hausmann), during transition to integrated fruit production for pipfruit in central Otago, New Zealand. N. Z. J. Crop Hortic. Sci. 38:255–273. doi:10.1080/01140671.2010.524189

Laboratory Testing of the Effects of 12 Environmentally Friendly Materials on *Mallada basalis* Walker and *Mallada desjardinsi* Navás

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Abstract

Dong, Y. J. and P. C. Hsu. 2024. Laboratory testing of the effects of 12 environmentally friendly materials on *Mallada basalis* Walker and *Mallada desjardinsi* Navás. J. Taiwan Agric. Res. 73(1):53–62.

This study demonstrated an indoor immersion method to test the impact of 12 biopesticides/non-registered environmentally friendly materials, including 10% citronella extract oil (Mold Stop), emulsified sunflower oil, neutralized phosphorous acid, lime sulfur mixture, Bordeaux mixture, potassium bicarbonate, 36% cinnamon extract oil microemulsifier (Black Asura), 40% cinnamon extract oil microemulsifier (Anthracnose Escape), plant oils mixture, neem oil, narrow-range oil, and *Bacillus thuringiensis*, on the eggs, larvae, pupae, and adults stages of both lacewing species, *Mallada basalis* Walker, and *Mallada desjardinsi* Navás. The experimental results showed that eight environmentally friendly materials, including Mold Stop, neutralized phosphorous acid, Bordeaux mixture, potassium bicarbonate, Black Shura, Anthracnose Escape, plant oils mixture, and *B. thuringiensis*, had no adverse effects on the eggs, larvae, pupae, and adults of both lacewing species. However, narrow-range oil, neem oil, emulsified sunflower oil, and lime sulfur mixture significantly caused higher mortality rates in the eggs, first-instar larvae, and pupae of the two lacewing species compared to the control group. *M. basalis* is one of the government-subsidized projects for farmers to purchase natural enemies, and commercially available products mainly consist of egg cards and larvae. According to the results of this experiment, farmers should avoid applying narrow-range oil, neem oil, emulsified sunflower oil, and lime sulfur mixture in the field where lacewing egg cards and larvae are released.

Key words: *Mallada basalis*, *Mallada desjardinsi*, Environmental friendly materials, Integrated pest management.

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曳引機附掛式甘藷苗插植機之研製

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摘要

林建志、邱相文。2024。曳引機附掛式甘藷苗插植機之研製。台灣農業研究 73(1):63–69。

本研究目的係開發一臺適合臺灣甘藷產業用之插植機械，將甘藷插植作業機械化與自動化，減少農民勞力輸出，提升田間作業的工作效率，增加甘藷產業競爭力，提高農民經濟所得，並達到農業輕勞力化，吸引年輕一代從事農業工作。本研究開發之甘藷苗插植機係利用傳統曳引機附掛式插植機構進行改良，採用人工供苗方式，平均直線速度為 1 m s^{-1}，行距 105 cm，株距 25 cm，插植深度 5–10 cm，作業效率約 1,000 m^2 h^{-1}，平均缺株率約 3.6%，與人工作業效率差距不大，但其將傳統蹲姿插植轉變為坐姿插植，大幅度降低勞力輸出與減少工作傷害發生機率，可有效吸引年輕人投入甘藷產業。

關鍵詞：甘藷、插植、機械化與自動化。

甘藷為我國重要食用作物與活化休耕地作物之一，根據農業部農糧署統計資料 (http://agr.afa.gov.tw/afa/afa_frame.jsp)，2018–2022 年本土甘藷種植面積平均約為 9,168 ha，平均產量約在 223.7 千噸以上，每年產值平均約為 32.7 億元 (2018–2022 年甘藷平均售價為每公斤 14.61 元)，產業價值高，但是隨著農村人口老化與勞力大量外移之關係，導致甘藷在種植 (插植) 時缺乏大量人工，故甘藷產業實有機械化與自動化之必要。

理想藷苗必須是生長機能旺盛，節間短，節數 7–8 節，有 5–6 枚以上葉片，且莖粗大，強壯與長度約 25–30 cm 的先端苗或二節苗。為配合機械作業採收，行距寬為 120 cm，株距 25–30 cm，每公頃約種植 28,000–33,000 株。插植方法直接影響甘藷塊根形狀的好壞、塊根的大小及收量的多少，因為近地面的節所生的藷數較多且大，品質較為優良。

目前於產業界幾無甘藷苗插植機械可使用，國人於 1986 年即已參考美國製二行式甘藷苗插植機研究開發的曳引機承載單人雙行盤式甘藷苗插植機，已能達成水平淺插的目標。Chang (2002) 於 2000 年時曾研製改良甘藷插植機具，其附掛於約 7.457 kW 乘座式水稻插秧機，人工乘坐於機器骨架上供苗。而插植機構設計為圓盤挾持式，以水平淺插方式種植，工作效率為 3.8 h ha^{-1}。在國外機型方面，日本發展舟式插植機構，大都以 1 人操作伴行與供苗，但作業速度不高，國內幾無引進應用。

國內外有許多學者研究插植機構，研究方向聚焦在插植機構的運動學分析，並找出其最佳化設計，例如 Yu *et al*. (2009) 從事偏心齒輪與偏圓齒輪插植機構運動學分析；Chen *et al*. (2010) 針對蔬菜移植機進行分析，利用 Visual Basic 模擬機構動作，找出蔬菜移植的最佳化動作；Guo & Zhang (2001) 對偏心行星齒輪進行運動學分析，找出偏心行星齒輪的運動學模型藉以提出改良方案。以上，並未包含甘藷插植作業機械或自動化的相關研究。因此，本研究目的在於開發一套適用於臺灣本土

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環境之甘藷插植機械，將插植作業機械化與自動化，提升工作效率，降低栽培成本，間接提高農民經濟收益。

下列將依甘藷苗插植機製作與田間試驗，逐項描述與討論。

甘藷苗插植機：

甘藷苗插植雛型機之電腦模型係利用 3D 繪圖軟體 Inventor 繪製，圖 1A 即為甘藷苗插植機分解圖。完成後利用電腦繪圖軟體進行組裝，利用人工方式判讀各零件間之相關性，以減少設計上之錯誤，圖 1B 即為甘藷苗插植機組合圖。待完成電腦模型組裝與確認後，以工程圖方式輸出圖檔並進行零件試作與組裝，圖 1C 即為完成後之附掛式甘藷苗插植機。

甘藷苗插植機除了本體外，尚分成開溝機構、插植系統及覆土機構。開溝機構係由 2 個圓盤犁所構成，位置在插植機本體前端，主要功能為破土開溝用。插植系統係由 1 個插植轉盤與 8 個插植機構所組成，位置在插植機本體中央，插植機構固定在插植轉盤上，係由夾取部 (夾具)、固定部 (置具) 及扭力彈簧所構成，功能為進行甘藷苗夾持與插植。覆土機構係由 2 個鎮壓輪所組成，位置在插植機本體後方，主要功能為進行覆土壓實作業，並配合齒輪組帶動插植系統作動，為避免鎮壓輪因摩擦力不足而發生打滑現象，本研究在鎮壓輪上面焊有 12 片鐵塊以增加抓地力。

甘藷苗插植機作動原理：

甘藷苗插植機屬於曳引機附掛式，利用曳引機提供動力行走，首先由開溝機構進行破土開溝作業，之後再利用插植系統進行插植作業。插植系統為輻射狀，以人工方式進行供苗作業，當操作者將甘藷苗放在置具上並對其施力時，扭力彈簧會作動迫使夾具與置具合併藉

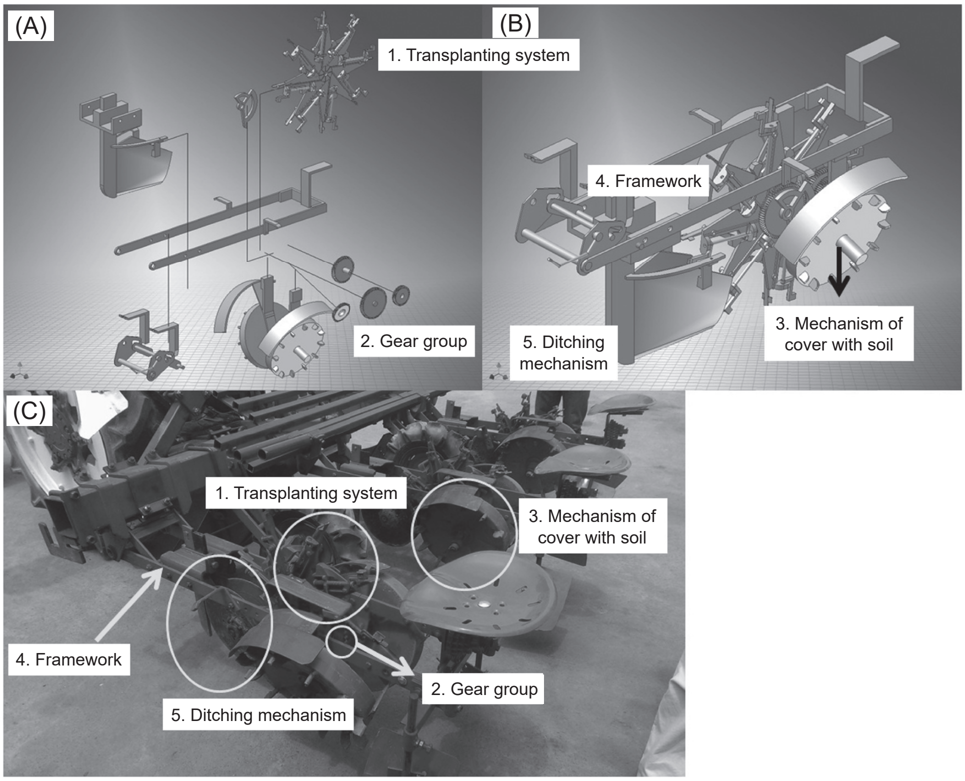

圖 1.　甘藷苗插植機。 (A) 甘藷苗插植機分解圖；(B) 甘藷苗插植機組合圖；(C) 附掛式甘藷苗插植機。

Fig. 1.　Sweet potato transplanter. (A) Exploded drawing of sweet potato transplanter; (B) assembling drawing of sweet potato transplanter; and (C) the tractor-mounted seedling transplanter for sweet potato.

以夾持甘藷苗，作業時鎮壓輪因曳引機移動開始旋轉產生動力，經由齒輪組輸出至插植轉盤，當插植轉盤運行至一定角度後，利用夾具上方特殊設計之機構配合插植機本體，迫使夾具與置具分離完成插植的動作，最後再由鎮壓輪進行覆土壓實作業。

式 (1) 係甘藷苗插植機株距計算公式，其中 d 係甘藷苗種植株距，D 係鎮壓輪直徑，e 則係齒輪比，可藉由調整鎮壓輪與插植系統間的齒輪比，或是鎮壓輪尺寸取得所需的插植株距。

$$d = \frac{\pi D}{8} \times e \tag{1}$$

插植型式則由開溝機構與插植系統相對位置所控制，若是配合得不好，將發生甘藷苗浮在土壤表層或整株埋在土壤等問題，導致插植失敗。

為找出開溝機構與插植系統之間的最佳相對位置，經由不斷試驗後，已找到最佳相對距離，為確認該位置是否屬於最佳化，遂進行甘藷插植試驗，研究增加或減少開溝機構與插植系統間的相對距離，對於插植成功率之影響。試驗水準依序為增加 (+ 5 cm)、正常 (0 cm) 及減少 (- 5 cm) 等 3 種，試驗方式為進行 3 次甘藷插植試驗，每次試驗插植 3 行，每行有 430 株甘藷苗，因此每次試驗有 1,290 株，計算因為開溝機構與插植系統相對位置改變，導致浮在土壤表面、埋在土壤內及插植成功數目，分別除以總插植甘藷苗數目計算百分比，藉此判斷線型設計之開溝機構與插植系統相對位置是否已達最適化。

田間試驗：

甘藷田間試驗田在嘉義新港頂菜園村，面積約為 0.2 ha (2,052 m^2，長度 108 m，寬度 19 m) 之試區 3 塊，其土壤質地為砂質土，土質較為鬆軟且排水性良好。試驗田在作業之前，需先利用迴轉犁進行第一次翻土犁耕作業，以確保試驗田作業環境良好。

本機進行田間試驗設定行距為 105 cm，株距 25 cm，插植深度 5–10 cm，每試區每次可插植 18 行，每行約可插植 430 株甘藷苗，試驗項目共有直線速度、作業效率及缺株率等 3 項。直線速度係本機在進行插植作業時，以直線距離 20 m 為基準，實際量測作業時間計算所得；當完成一行甘藷苗插植作業後，為了安全考量，操作者須要離開甘藷苗插植機，待機械舉升離開田間移動至另一行落地後，操作者方能乘上機械繼續操作，故轉彎時間因人為因素差異極大，不列入調查項目；作業效率係記錄甘藷苗插植機於每塊試驗田作業所需時間，取平均值計算所得；由於本機屬於人工供苗，常發生操作者供苗不及導致失敗，此部分損失我們稱之為供苗失敗數，供苗失敗率 (supply seedling failure rate) 即為供苗失敗數與本次試驗甘藷苗總數之比值計算其百分比所得；另一方面也會因農地之因素，導致部分甘藷苗未插入土壤內，此部分損失我們稱之為插植失敗數，插植失敗率 (transplant failure rate) 即為插植失敗數與本次試驗甘藷苗總數之比值計算其百分比所得；缺株率 (rate of vacant plants) 則為供苗失敗率與插植失敗率之總和。

本研究田間試驗之附掛式甘藷苗插植機如圖 1C 所示，其中曳引機需要 1 名駕駛，後面附掛 3 組甘藷苗插植機，每組需要 1 名操作者，共需 4 名操作者，每次動作可同時插植 3 行。圖 2 為附掛式甘藷苗插植機田間試驗情形，由圖可知試驗情況良好，本機可正常進行甘藷插植作業。

甘藷插植試驗結果如表 1 所示，其中 Type 1 為甘藷苗浮在土壤表面所占百分比，產生此種現象之原因為機構放苗時間太晚或是覆土時間太早，Type 2 為甘藷苗埋在土壤內所占百分比，產生此種現象之原因為機構放苗時間太早或是覆土時間太晚，Type 3 為甘藷苗插植成功所占百分比。

表 2 為附掛式甘藷苗插植機田間作業性能表，由表可知本機直線速度約為 1 m s^{-1}，轉彎時間介於 20–150 s 之間，作業效率約 1,060 m^2 h^{-1}，缺株率約 3.6%。

插植試驗完成後至試驗田調查甘藷苗栽培情形，圖 3A 為甘藷苗插植 1 mo 後田間生長情形，圖 3B 為收穫時之甘藷，由圖可知甘藷苗生長情況良好，機械插植不會影響甘藷生長，本機應可有效取代現在的人工插植方式。

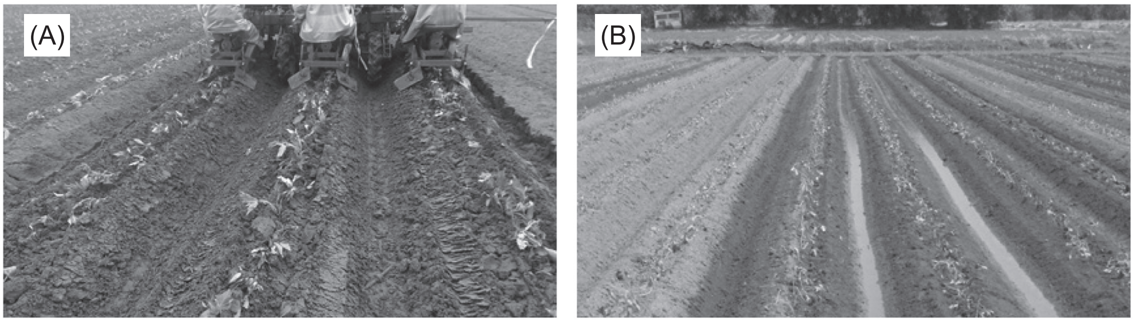

圖 2.　附掛式甘藷苗插植機田間試驗情形。(A) 本機進行插植試驗時；(B) 本機插植完成後之試驗田。
Fig. 2.　Field trial situation. (A) Transplanting; and (B) after the transplanting experiment.

表 1.　插植成功率 (%) 試驗結果。
Table 1.　Transplant success rate (%).

	+ 5 cm			0 cm			- 5 cm		
Characteristic	Type 1[z]	Type 2[y]	Type 3[x]	Type 1	Type 2	Type 3	Type 1	Type 2	Type 3
First	2.6	35.6	61.8	0.6	1.0	98.4	38.7	7.2	54.1
Second	3.1	23.1	73.8	0.7	0.6	98.7	29.8	0.4	69.8
Third	4.5	29.8	65.7	0.9	0.9	98.2	32.4	9.4	58.2
Avg.	3.4	26.2	70.4	0.7	0.8	98.4	33.6	5.7	60.7

[z] On the soil.
[y] Inside the soil.
[x] Correct.

表 2.　附掛式甘藷苗插植機田間作業性能表。
Table 2.　Operation performance of the tractor-mounted seeding transplanter for Sweet Potato.

No.	I	II	III	Avg.
Area (m^2)	2,095.2	2,095.2	2,095.2	2,095.2
Speed ($m\ s^{-1}$)	1.002	1.002	0.998	1.000
Time (s)	6,456	7,536	7,177	
Efficiency ($m^2\ h^{-1}$)	1,168.33	990.57	1,023.87	1,060.92
Supply seedling failure rate (%)	2.2	2.1	2.1	2.1
Transplant failure rate (%)	1.9	1.0	1.5	1.5
Rate of vacant plants[z] (%)	4.1	3.1	3.6	3.6

[z] Rate of vacant plants (%) = supply seedling failure rate + transplant failure rate.

從甘藷插植試驗得知不論是增加或減少開溝機構與插植系統相對位置，都會降低插植成功率，增加相對距離，Type 2 比例增加；減少相對距離，Type 1 比例則增加，由上述現象可判定，目前本機開溝機構與插植機構相對位置之設計已達最佳化。人工調查時缺株率除了人工供苗不及產生外，尚有因試驗田地因素導致之插植失敗率，其造成原因，一為圖 4A 田區低窪，二為圖 4B 試驗田內有部分雜物，此兩點皆會造成土壤無法有效聚集，開溝機構無法正常作動，造成甘藷苗落在土壤表面，無法插植入土壤內，導致插植失敗，此部分可利用田間整地方式處理，若處理得當，可再降低本機缺株率。

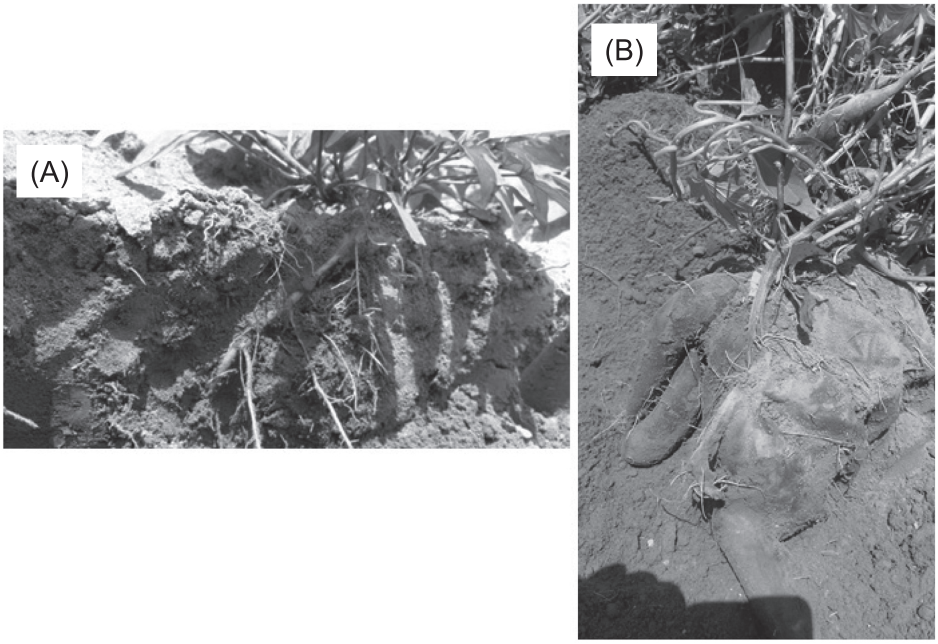

圖 3. 甘藷苗插植後田間生長情形。(A) 為插植後 1 mo；(B) 收穫時。

Fig. 3. Field growth situation. (A) One month later; and (B) when harvested.

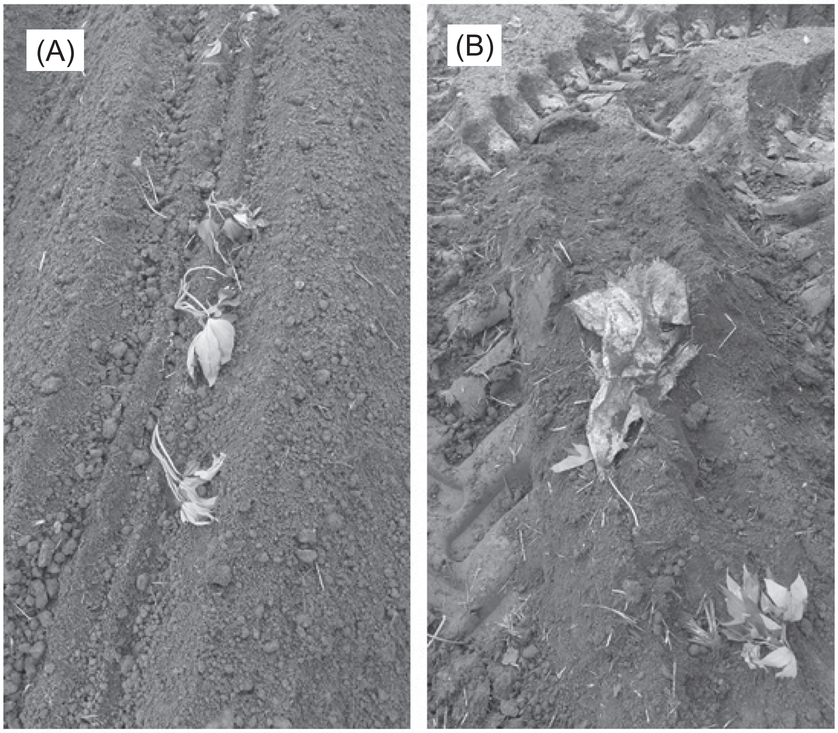

圖 4. 造成插植失敗原因。 (A) 田區低窪；(B) 試驗田內有雜物。

Fig. 4. Reasons for failure of transplanting. (A) Low-lying place; and (B) there was debris in the field.

本研究開發之附掛式甘藷苗插植機 (以下簡稱本機) 與 Chang (2002) 研發之乘座式甘藷苗插植機相似，屬於附掛式機械，並將操作者插植作業姿勢，由傳統蹲姿轉變為坐姿，將甘藷插植作業輕勞力化，降低工作傷害發生機率。Chang (2002) 研發的插植機構係採用圓盤夾持式，由 2 個直徑相同之圓盤構成，機構簡單，插植株距係利用圓盤上記號進行調整，由操作者目視記號供苗，容易因長時間精神集中造成眼睛疲勞，導致缺株現象產生，且屬於水平式淺插，並不適用於臺灣現行的甘藷產業；本機之插植機構係採用插植機構式，插植株距由齒輪比進行調整，操作者僅需將甘藷苗置於插植機構上，不易造成缺株，且屬於舟式淺插，符合臺灣甘藷產業現況。甘藷苗供苗方式兩機皆採用人工供苗，原因在於甘藷苗長度約 25–30 cm，節間短，節數 7–8 節，有 5–6 枚以上葉片，而插植株距約在 25 cm，以現行長度 100 m 之田地而言，每行需插植 400 株甘藷苗，若全部置於供苗盤上，其枝節容易互相勾纏，不易分離，若採用機械式強制分離，容易造成甘藷苗上的枝節與葉片掉落，影響品質，故兩機皆採用人工供苗，減少枝節或葉片掉落現象發生。

本研究已成功開發出附掛式甘藷苗插植機，並已找出開溝機構與插植機構的最佳化相對距離，可成功進行甘藷插植作業，依據田間試驗結果，本機甘藷苗插植行距為 105 cm，株距 25 cm，插植深度 5–10 cm，作業效率約 1,060 m^2 h^{-1}，缺株率約 3.6 %。造成缺株率主因包括：(1) 人工供苗不及，導致供苗失敗率；(2) 甘藷苗落在土壤表面，未插植入土壤內，造成插植失敗率。其中插植失敗率發生主因，係由試驗田地不良所衍生之問題，若透過整地方式加以管理改善，則可降低缺株率。本機將甘藷苗插植作業由傳統蹲姿轉變為坐姿，可將甘藷苗插植作業朝向輕勞力化，並降低工作傷害發生機率，期可吸引年輕農民投入甘藷產業。

引用文獻

Chang, C. F. 2002. The study and improvement of a riding type transplanter for sweet potato. Bull. Taoyuan Dis. Agric. Res. Exten. Stat. 49:15–23. (in Chinese with English abstract) doi:10.29567/ZH-WHGX.200206.0002

Chen, J., B. Wang, G. Ren, and Q. Huang. 2010. Kinematics modeling and parameters analysis of seven-linkage vegetable seedling transplanting mechanism. Trans. Chin. Soc. Agric. Mach. 41(12):48–53. (in Chinese with English abstract) doi:10.3969/j.issn.1000-1298.2010.12.010

Guo, L. S. and W. J. Zhang. 2001. Kinematic analysis of a rice transplanting mechanism with eccentric planetary gear trains. Mech. Mach. Theory. 36:1175–1188. doi:10.1016/S0094-114X(01)00052-0

Yu, G. H., M. B. Qian, Y. Zhao, and C. Y. Wu. 2009. Analysis of kinematic principle of transplanting mechanism with eccentric gears and non-circular gears. Trans. Chin. Soc. Agric. Mach. 40(3):81–84. (in Chinese with English abstract)

Development of Tractor-Mounted Seedling Transplanter for Sweet Potato

Jian-Jhih Lin[1] and Hsiang-Wen Chiu[2,*]

Abstract

Lin, J. J. and H. W. Chiu. 2024. Development of tractor-mounted seedling transplanter for sweet potato. J. Taiwan Agric. Res. 73(1):63–69.

The purpose of this study was to develop a transplanting machine to meet the demand of Taiwan's sweet potato industry, to actuate the mechanization and automation of the sweet potato planting operation, as well as to reduce the farmers' labor. This study also intended to improve the efficiency of field operations and economic income, the competitiveness of the sweet potato industry to achieve labor-saving in agriculture and to attract the younger to engage in agricultural operations. The sweet potato transplanting machine developed in this research is to reform the traditional tractor-mounted type of transplant mechanism, which adopts a manual seedling feeding method. Field experiments revealed that with the average linear speed of 1 m s^{-1}, row spacing of 105 cm, plant spacing of 25 cm, and planting depth of 5–10 cm, the operating efficiency is about 1,000 m^2 h^{-1}, and the average of the planting loss rate is about 3.6%. There was no difference in operation efficiency of using this machine as compared with the manual. However, it changes the working posture of seeding supplying workers from the squatting position to the sitting position, thus saving labor and reducing the incidence of work-related injuries and attracting young people to work in the sweet potato industry.

Key words: Sweet potato, Transplant, Mechanization and automation.

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